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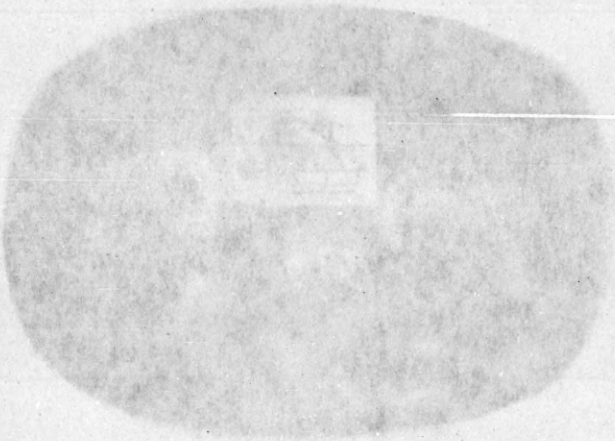

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THE TRUE STRESS-STRAIN TENSION TEST—ITS ROLE IN MODERN MATERIALS TESTING.

PART II.

BY

C. W. MACGREGOR.*

The fundamentals of the true stress-strain tension test, the methods used and the general relationships obtained were discussed in Part I of this paper. In addition the effects of such mechanical conditions, as high and low testing temperatures, the speed of testing, and the proportions of the test bar on true stress-strain values, were described.

In Part II, the effects of various metallurgical conditions on the true stress-strain properties will be reported together with a description of the use of this form of test in connection with the metal forming processes and other materials testing problems.

VII. THE EFFECTS OF SOME METALLURGICAL CONDITIONS AS REVEALED BY TRUE STRESS AND STRAIN VALUES.

The true stress-strain tension test is particularly well suited to bring out the effects of different metallurgical conditions on fundamental material properties. It is proposed here to discuss the effects of such conditions as heat-treatment, alloying additions, cold work, overheating, directionality, etc., on the true stress-strain values.

Heat-Treatment.

The general effect of heat-treatment by quenching and tempering a carbon steel on the true stress-strain properties is illustrated in Figs. 16 to 18 inclusive. These results were obtained [11] on uniform 0.505″

* Professor of Applied Mechanics, Massachusetts Institute of Technology, Cambridge, Mass.

[11] C. W. MacGregor and J. C. Fisher, "Relations Between the Notched Beam Impact Test and the Static Tension Test," *Journal of Applied Mechanics*, March 1944, pp. 1–7.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

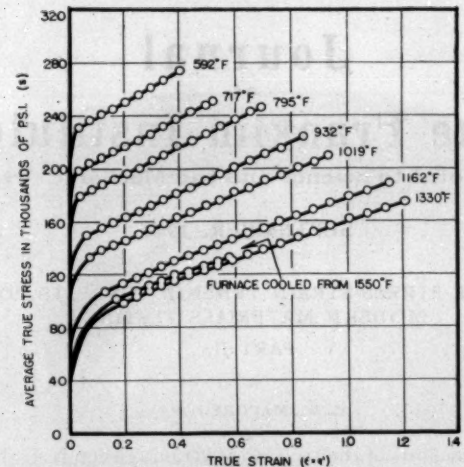

FIG.16 TRUE STRESS-STRAIN CURVES FOR S.A.E.-1045 STEEL QUENCHED FROM 1550°F AND DRAWN AT THE TEMPERATURES INDICATED.

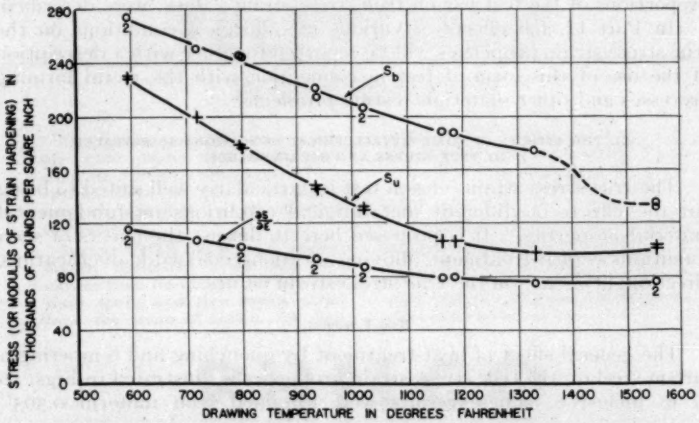
STRESS (OR MODULUS OF STRAIN HARDENING) IN THOUSANDS OF POUNDS PER SQUARE INCH
DRAWING TEMPERATURE IN DEGREES FAHRENHEIT

FIG.17 VALUES OF TRUE FRACTURE STRESS S_b, TRUE MAXIMUM LOAD STRESS S_u AND MINIMUM $\frac{ds}{d\varepsilon}$ FOR S.A.E.-1045 STEEL AS AFFECTED BY DRAWING TEMPERATURES.

diameter tension test bars of S.A.E.—1045 steel which were quenched from 1550° F. in water and tempered at the various drawing temperatures indicated. At least two specimens were tested for each condition. A somewhat similar set of experiments were carried out independently by J. H. Hollomon of the Watertown Arsenal.[12] Figure 16 shows that linear relationships maintain for each drawing temperature from the maximum load point to fracture. The *decrease* of the true stress at the maximum load S_u, the true stress at fracture S_b and the minimum modulus of strain hardening $\partial S/\partial \epsilon$ with higher drawing temperatures is indicated in Fig. 17. Figure 18 shows the effect of different drawing

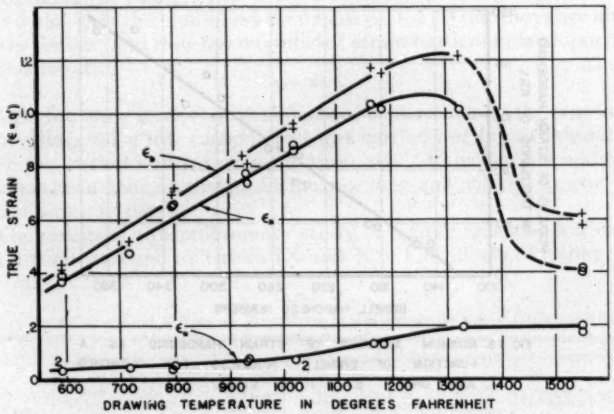

FIG. 18 TRUE STRAIN VALUES FOR S.A.E.-1045 STEEL AT FRACTURE ϵ_b, AT $P_{max.}$ OF VALUE ϵ_u, AND DURING LOCAL NECKING ϵ_n, AS AFFECTED BY DRAWING TEMPERATURE

temperatures on the true strain values. It can be seen that the true local necking and fracture strains are affected in the same manner while the true uniform strain reacts in a different fashion to increases in the drawing temperature.

The relationship between the Brinell Hardness and the minimum modulus of strain hardening $\partial S/\partial \epsilon$ for this steel is shown in Fig. 19. The increased hardness numbers refer to the test bars having lower drawing temperatures. An approximate linear relationship is thus present between the Brinell Hardness and the minimum modulus of strain hardening for this steel.

[12] J. H. Hollomon, "The Effect of Heat Treatment and Carbon Content on the Work Hardening Characteristics of Several Steels," *Trans. of Am. Soc. for Metals*, Vol. XXXII, 1944, pp. 123–131.

An investigation of the correlation between other types of stress-strain curves and the Meyer Hardness Number has been reported by O'Neill.[13]

The effects of different micro-constituents in steels produced by isothermal reactions at different temperatures before the test on the true stress-strain properties have been investigated by Gensamer [14] and his collaborators. This represents the first controlled attempt as far as the author is aware to correlate the true stress and strain properties with the micro-structure of the steel. Reaction temperatures of 375° C. to 700° C. were used. Interlammelar pearlite was received down to

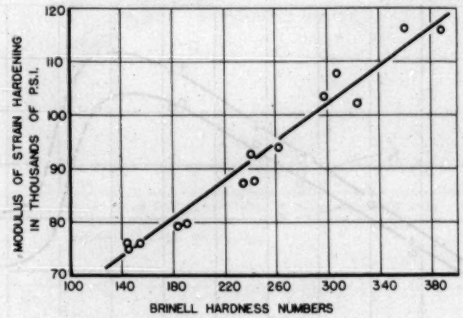

FIG. 19. MINIMUM MODULUS OF STRAIN HARDENING AS A FUNCTION OF BRINELL HARDNESS FOR QUENCHED AND DRAWN SAE 1045 STEEL.

500° C. At 475° C. both pearlite and bainite were present and no pearlite observed at the lower temperatures. It was shown by Gensamer for the plain carbon eutectoid steel used that as the reaction temperatures were increased (1) the true stresses at fracture *decreased;* (2) the true fracture strains *decreased*, then *increased*, followed by a *decrease;* and (3) the minimum modulus of strain hardening was relatively unaffected.

Alloying Additions.

The effects of alloying elements in solid solution on the strength and rate of strain hardening of ferrites of substantially constant grain size as revealed by true stress-strain curves have been reported recently

[13] H. O'Neill, "The Significance of Tensile and Other Mechanical Test Properties of Metals," presented at the Applied Mechanics Group Meeting of the Institution of Mechanical Engineers, London, England, June 18, 1943.

[14] M. Gensamer, E. B. Pearsall, G. V. Smith, "The Mechanical Properties of the Isothermal Decomposition Products of Austenite," *Trans. of the A. S. M.*, Vol. 28, 1940, pp. 380–395.

by C. E. Lacy [15] and M. Gensamer.[15] Some 30 iron binary alloys were prepared with chromium, cobalt, vanadium, aluminum, nickel, molybdenum, tungsten, silicon, titanium, and beryllium as the alloying elements. Also certain ternary and quaternary alloys were studied. In general the alloys contained 1 to 3 per cent. atomic solute. The results of Lacy and Gensamer showed that in general increasing additions of any of these alloying elements brought about an *increase* in the strength and a *lowering* of the ductility. Likewise, larger additions of an alloying element tended to *increase* the minimum modulus of strain hardening and the intercept S_i of the true stress-strain curve obtained by extending the straight line portion to zero true strain. Their results showed also that the true stress-strain curves for all the alloys are almost exactly similar, and that the modulus of strain hardening is proportional to the strength.

Cold Work.

A preliminary study[16] of the effects of cold-rolling on the true stress-strain values for a low carbon steel was carried out in our laboratories under the author's direction some time ago. Considerable additional work has been done on this problem since then and will be reported later on in a separate paper.

The results of this preliminary study on a fully annealed low carbon steel are summarized in Tables IX and X. The effects of rolling up to

TABLE IX.

The Effect of Cold-Rolling on True Stress-Strain Values for a Low Carbon Steel (in Rolling Direction).

Per Cent. Reduction.	True Stress at Yield Point Lbs./In.².	S_u True Stress at Max. Load Lbs./In.².	S_b True Stress at Fracture Lbs./In.².	True Strain at Max. Load $\epsilon_u = q_u'$.	True Strain at Fracture $\epsilon_b = q_b'$.	True Local Necking Strain $\epsilon_n = q_n'$.	Mod. of Strain Hardening $\frac{\partial S}{\partial \epsilon}$ Lbs./In.².	Intercept S_i Lbs./In.².
0	30,000	66,900	107,800	0.225	1.038	0.813	47,600	57,000
5	51,100	72,100	107,000	0.109	0.831	0.722	46,000	68,000
10	60,800	77,500	107,000	0.088	0.760	0.672	42,600	74,000
15	73,900	82,950	108,000	0.050	0.662	0.612	40,000	81,000
30	80,100	91,200	108,000	0.027	0.485	0.458	39,000	91,000

Note: All bars rolled in one pass to per cent. reductions indicated with exception of the 30 per cent. reduction which was rolled in 6 equal passes (unreversed). At least 2 specimens were tested in each condition and these were cut from the rolled bars in directions parallel to the rolling direction.

[15] C. E. Lacy and M. Gensamer, "The Tensile Properties of Alloyed Ferrites," presented at the 25th Annual Convention of the Amer. Soc. for Metals, Chicago, October 1943.

[16] F. J. Mehringer, "The Effects of Cold Working on the True Stress-Strain Properties of Low Carbon Steel," Term Report in course Plasticity Research, Massachusetts Institute of Technology, 1942.

TABLE X.

The Effect of Cold-Rolling on True Stress-Strain Values for a Low Carbon Steel (Transverse to Rolling Direction).

Per Cent. Reduction.	True Stress at Yield Point Lbs./In.².	S_u True Stress at Max. Load Lbs./In.².	S_b True Stress at Fracture Lbs./In.².	True Strain at Max. Load $\epsilon_u = q_u'$.	True Strain at Fracture $\epsilon_b = q_b'$.	True Local Necking Strain $\epsilon_n = q_n'$.	Mod. of Strain Hardening $\frac{\partial S}{\partial \epsilon}$ Lbs./In.².	Intercept S_i Lbs./In.².
5	50,700	72,500	104,000	0.111	0.696	0.585	52,700	66,000
10	60,400	77,400	105,000	0.076	0.644	0.568	45,500	73,000
15	67,800	86,850	104,500	0.061	0.544	0.483	36,600	83,000
30	82,100	97,600	103,000	0.033	0.362	0.329	20,000	97,000

Note: All bars rolled in one pass to per cent. reductions indicated with exception of the 30 per cent. reduction which was rolled in 6 equal passes (unreversed).

30 per cent. reductions on the properties parallel to the direction of rolling are listed in Table IX and on the properties transverse thereto in Table X. For both directions, it is seen that the true stresses at the yield point and at the maximum loads *increase* with the heavier reductions in rolling. It will be noted, however, that for reductions up to 30 per cent., the true fracture stress is practically *unaffected* by the magnitude of the reduction. More recent experimental evidence substantiates this, but indicates that reductions greater than 30 per cent. show some influence on the fracture stress.

These tables also indicate that the true uniform, local necking, and fracture strains all *decrease* with increased reductions in rolling.

Another interesting feature is the effect of cold-rolling on the minimum modulus of strain hardening. As can be seen, the effect of larger reductions in rolling is to continuously *decrease* the minimum modulus of strain hardening.

The fact that heavier reductions in rolling *increase* the true stress at the maximum load S_u, and *decrease* the minimum modulus of strain hardening $\partial S/\partial \epsilon$, necessarily results in *increased* values of the intercept S_i obtained by extending the linear part of the true stress-strain curve to the stress axis of zero true strain, as shown in Tables X and IX.

Over-Heating.

The change in the true stress-strain properties produced by over-heating is still under investigation in our laboratories at the present time. It is known that over-heating may occur in certain forging operations and it has been found that the true stress-strain tension test may disclose these effects in a more discriminating way than will be shown by the usual form of tension test.

Although more work needs to be done on this problem, there is sufficient evidence to suggest that the general effect of over-heating on

the steels tested is to reduce the true fracture and local necking strains, and the true fracture stress, while the true uniform strain is left relatively unaffected.

Directional Properties.

The effects of anisotropy in materials can be portrayed through the use of true stress-strain values in a very discriminating fashion. This has been shown by Johnston and Opila.[17] The following will describe the results of some tests conducted in our laboratories on the same problem.

A comparison is made in Table XI of the relative merits of the ordinary physical properties and the true stress-strain values in de-

TABLE XI.

Comparison of Ordinary Physical Properties and True Stress-Strain Values in Revealing Directional Effects (Avg. of Two or More Specimens)

Direction Relative to Rolling.	Ordinary Properties.				True Stress-Strain Values.					
	Yield Strength Lbs./In.².	Tensile Strength Lbs./In.².	Elong. Per Cent. 1.2 Inches.	Red. of Area Per Cent.	S_u Lbs./In.².	S_b Lbs./In.².	ϵ_u.	ϵ_b.	ϵ_n.	$\frac{\partial S}{\partial \epsilon}$ Lbs./In.².
0°	41,600	64,800	34.9	58.3	81,200	118,700	0.224	0.874	0.650	57,500
30°	45,300	65,600	37.8	56.9	81,800	118,000	0.215	0.839	0.624	58,000
45°	48,000	65,800	33.6	55.3	81,700	115,000	0.214	0.783	0.569	59,600
60°	47,300	66,100	28.2	51.2	82,300	114,000	0.221	0.719	0.498	63,600
90°	44,500	65,600	28.3	37.5	82,400	96,600	0.227	0.466	0.239	60,900

Note: Yield strength was based on 0.001" change of diameter of 0.300".

S_u—True Stress at Max. Load.
S_b—True Fracture Stress.
ϵ_u—True Uniform Strain.
ϵ_b—True Fracture Strain.
ϵ_n—True Local Necking Strain.
$\frac{\partial S}{\partial \epsilon}$—Minimum Modulus of Strain Hardening.

Material—Low Carbon Steel Annealed at 1650° F. and Furnace Cooled—Composition—C—0.19%, S—0.118%, P—0.092%, Mn—0.85%, Si—0.01%.

picting directional effects in metals. The material in this case is fully annealed mild steel of the composition listed in the table. The test specimens were cut from the bar at the inclinations to the axis indicated immediately after the bar had been given a full annealing treatment.

It can be seen that as regards stress values, the true stress at the maximum load is somewhat more consistent in its variation with the inclination to the bar axis than the ordinary tensile strength. Although

[17] B. Johnston and F. Opila, "Compression and Tension Tests of Structural Alloys," *Proceedings of the American Society for Testing of Materials*, Vol. 41, 1941, pp. 552–570.

these differences are slight and would hardly justify the use of true stress and strain values by themselves, a more striking difference is seen in the variation of the true fracture stress with the direction. Contrary to the slight *increase* in the true stress at the maximum load as the direction changes from axial to transverse in the original stock, the true fracture stress *decreases* substantially. This is occasioned by the loss in ductility from the maximum load point to fracture.

Comparing ductility values, it may be seen that the ordinary per cent. elongation in 1.2 inches decreases by 18.9 per cent. and the ordinary reduction of area decreases by 35.6 per cent. as the direction of stressing changes from the original rolling direction to that at 90° to it. On the other hand, the true strain values show that directionality has little effect on the true uniform strain ϵ_u but has a pronounced effect on both the true fracture strain ϵ_b and the true local necking strain ϵ_n. In fact, the true fracture strain ϵ_b decreases by 46.7 per cent. and the true local necking strain decreases by 63.2 per cent. in proceeding from the rolling direction to that at 90° to the rolling direction. Consequently, it may be seen that the major effect of directionality is shown by its influence on the true local necking strain ϵ_n.

It may also be noted that, as the direction of testing is changed from the rolling direction, the minimum modulus of strain hardening also increases as shown in Table XI.

VIII. THE ROLE OF THE TRUE STRESS-STRAIN TENSION TEST.

From the preceding discussion it can be concluded that the tension test in which true stress and strain values are recorded is quite useful in its own right. The effects of various mechanical and metallurgical conditions on the fundamental true stress and strain properties can be shown in a convenient and discriminating manner. Although most of the previous discussion referred to uniform round or flat specimens, it is not restricted to this since the method can and has been applied to notched tensile specimens as well. Some of the latter will be referred to later on.

In addition to these functions, however, the true stress-strain tension test is particularly useful in connection with other forms of tests and metal forming processes. Its use in conjunction with these not only yields new information but in many cases provides a correlation between them and the tension test not possible by conventional methods. It is the object of the following to discuss its role in relation to several other forms of tests and processes.

Metal Forming Processes.

The use of true stress-strain values in connection with wire drawing through dies of small angles and under well lubricated conditions has been discussed earlier.[4]

As has been pointed out by C. L. Eksergian,[18] a high uniform strain is desirable in many instances of deep drawing, such as in the case of the drawing of automobile fenders, etc. On the other hand, Eksergian also calls attention to the fact that in certain die formations in which the metal is so locked that the unconfined stretch is very small, a high local strain is of necessity required. Examples of the latter would be in drawing the bead in a car door or in the formation of sharp bend radii. Consequently, this indicates that in the metal drawing problem, depending upon the shape to be drawn, both the true uniform and true local necking strains may be of guiding significance. These may be obtained conveniently from the true stress-strain tension test.

A special type of deep drawing problem, namely the drawing of cylindrical cups without ironing, was investigated under the author's direction by E. L. Bartholomew, Jr.,[19] at the Massachusetts Institute of Technology. Both drawing tests and true stress-strain tension tests were made on brass, aluminum and deep drawing S.A.E.—1020 sheet steel. The test results disclosed a rather close correlation between the cupping tests and the true stress-strain tension tests. It could be concluded that for the materials tested (1) the maximum true tensile vertical wall stress in the cup for maximum blank diameter compared favorably with the true stress at the maximum load; (2) the maximum blank diameter which could be drawn successfully (the limit of drawability) can be predicted from the true stress-strain curve; (3) the true fracture stress at the critical section in the cup agreed well with the true fracture stress in the tension test; (4) the limiting true uniform strain ϵ_u shows a more definite relationship to the maximum per cent. reduction in cupping than does the ordinary per cent. elongation in 2 inches.

In the rolling of metals, an accurate picture of the strain distributions may be obtained by using the true strain definitions.[20] The values so obtained may be compared with those obtained in the tension or compression test. Further work on this is under way in our laboratories.

Notched-Beam Impact Tests.

The standard notched-beam impact test (Charpy or Izod) has proved to be of great value in materials testing mainly as a sensitive control of the mechanical and metallurgical state of the material. It has been shown that often two identical mill heats of the same steel will show practically the same ordinary tension test properties and still differ widely in their notched-beam impact values. One of the shortcomings

[18] C. L. Eksergian, "The Plastic Behavior of Metal in Drawing," presented at the Annual Meeting of the A. S. M. E. in New York, December 1926.

[19] E. L. Bartholomew, Jr., "Stress-Strain Measurements in the Drawing of Cylindrical Cups," *Transactions of the Amer. Soc. for Metals*, Vol. XXXI, No. 3, September 1943, pp. 582–593.

[20] C. W. MacGregor and L. F. Coffin, Jr., "The Distribution of Strains in the Rolling Process," *Journal of Applied Mechanics*, March 1943, A13–A20.

of the test, however, lies in the fact that it provides only total energy values giving no information on stress-strain relations for the material in question. The notched-beam impact test has always been difficult to correlate with other forms of tests.

Some time ago, an experimental program [11] was undertaken in our laboratories with the object of ascertaining if the static tension test, in its more rational form employing true stress-strain values, could be used to show essentially the same effects of certain mechanical and metallurgical conditions on energy values as are portrayed by the notched-beam impact test. If this were possible, the tension test would have the added advantage of supplying stress-strain information not determined in the other form of test.

Several materials were selected namely, the S.A.E. steels—1020, —1112, —1045 and —3140. With the exception of the S.A.E.—1045 steel, all were given a full annealing treatment. Two types of tension specimens were prepared; namely, standard uniform 0.505 inch diameter test bars and special notched specimens; the latter as indicated in Fig. 20

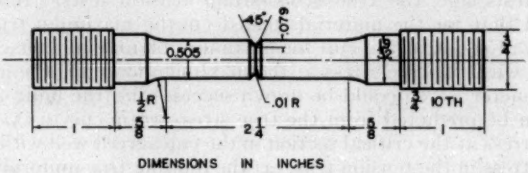

FIG. 20 NOTCHED TENSILE SPECIMEN.

contained a notch of the same form as used in the Charpy impact specimens. Also standard Charpy impact specimens were prepared from the same materials.

The S.A.E.—1045 steel was quenched from 1550° F. and drawn at various temperatures. The other materials were tested at different testing temperatures.

A comparison was then made of the effect of heat-treatment (S.A.E. —1045) and testing temperatures (the other steels) on the variation of the *energy absorbed per unit of deformed volume* from the notched-beam impact tests and from the static tension tests of the true stress-strain type.

Figure 21 shows that while the uniform tension specimens showed some similarity to the notched-beam impact specimens as regards the effects of different drawing temperatures on the energy absorbed per unit of volume, a much better correlation is given by the notched tension specimens. In fact, the notched static tension specimens portray essentially the same effect of drawing temperatures as revealed by the Charpy impact specimens. The curves only differ by a constant factor

which is brought about by the fact that the notched-beam specimens yield an average of the specific energies over the deformed portions of the test specimens, while the corresponding values for the notched tension specimens are measured at the most severely deformed portions only.

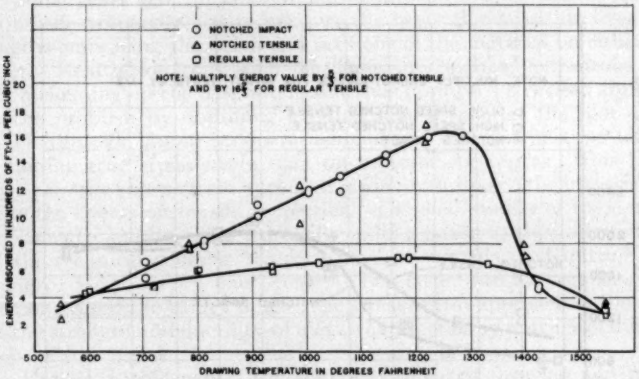

FIG. 21 SPECIFIC ENERGY FOR FRACTURE AS DETERMINED BY NOTCHED BEAM IMPACT, NOTCHED TENSION, AND UNIFORM TENSION TESTS AS A FUNCTION OF DRAWING TEMPERATURE FOR S.A.E.-1045 STEEL.

Another example of the correlation obtained between the Charpy impact and the true stress-strain tension test is shown in Fig. 22. In this case, it may be seen that the effect of testing temperatures on the specific energies to fracture for the S.A.E.—3140 steel is essentially the same for both types of tests. Similar results were obtained for the other materials tested.

This shows that for these materials and testing conditions, a reasonably good correlation exists between the notched beam impact test and the static notched tension test when true stress-strain values are employed.

Fatigue Tests.

Many attempts have been made in the past to correlate the results of the ordinary form of tension test with those obtained in various types of fatigue tests with only moderate success. It is too early to determine whether in general a better correlation will exist between fatigue values and the results of the true stress-strain tension test. Many more experiments will have to be carried out in order to establish this fact definitely.

Experiments reported by J. M. Lessells,[21] however, indicate the possibility that fatigue results may correlate better with the true stress-strain tension test than with the routine tension test. Lessells has shown that for certain alloy steels the endurance limit correlates much better with the true fracture stress in the tension test than with the ordinary tensile strength.

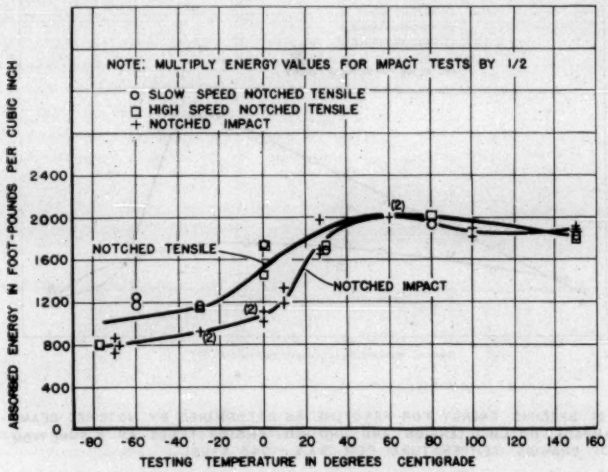

FIG. 22 ENERGY PER UNIT OF DEFORMED VOLUME FOR S.A.E. 3140 STEEL AS A FUNCTION OF TESTING TEMPERATURE FROM NOTCHED TENSION AND NOTCHED BEAM IMPACT TESTS.

As a further example illustrating the possible use of true stress-strain data in relation to the fatigue problem, Godfrey [22] has reported that the number of 180° bends to failure for cold-drawn steel wire correlate very well with the true local necking strain obtained from tension tests on the same material. The bend test used by Godfrey is essentially an accelerated fatigue test.

Notch-Effect Tests.

It has become increasingly evident in recent years that notches are playing a very important role in our machine elements and structures. Photoelastic tests have revealed the presence of high stress concentra-

[21] J. M. Lessells, "A Request for Fatigue Information" (Letter to the Editor), *The Engineer*, Vol. 173, 1942, p. 208.

[22] H. J. Godfrey, "The Fatigue and Bending Properties of Cold-Drawn Steel Wire," *Trans. of the Amer. Soc. for Metals*, Vol. XXIX, No. 1, March 1941, p. 133.

tions near such geometrical irregularities and most designers today try to minimize these effects by proper design wherever possible. In most cases, however, for practical reasons it is not possible to remove their effects entirely. Their importance has been reflected in increased activity along these lines in materials testing.

Some years ago, the conventional approach to the effect of notches on tensile properties was to measure the over-all axial strain over gage lengths embracing the notch and portions of the material on either side of it. Realization that such measurements include extraneous data often clouding up the true notch effect has prompted a revised approach to the problem by obtaining average axial strains at the root of the notch through lateral strain measurements of the same type used in obtaining true stress-strain data on uniform specimens. This means that the true stress-strain approach is ideally suited to the investigation of notch effects on tensile properties. Detailed studies of these effects on strength and ductility, especially in its relation to the determination of the technical cohesive strength have been made by Kuntze,[23] Gensamer,[24] McAdam [25,26] and Mebs.[26] The latter two authors have ably demonstrated the utility of the true stress-strain approach in the study of the strength and ductility of metals as affected by notches of different depths and angles.

Earlier in this paper, the effects of different drawing and testing temperatures on the true stress-strain properties of various metals obtained with *uniform* specimens was described. Since then additional data have been obtained in our laboratories on the effects of drawing and testing temperatures on the same materials using the *notched* specimen shown in Fig. 20. The results are summarized in Figs. 23 to 26 inclusive.

Comparing Figs. 17 and 18 for the uniform diameter test bars with Fig. 23 for the notched specimens of the same material (S.A.E.—1045), it will be seen that both notched and uniform specimens exhibit about the same qualitative effect of the *drawing temperatures* on the true fracture stress and strain properties.

It may be seen from Figs. 24 to 26 inclusive that while the *notched* specimens showed considerable decrease in the true fracture strain as the *testing temperature* was lowered, the true fracture stress either re-

[23] W. Kuntze, "Kohäsionsfestigkeit," Mitteilungen aus der deutscher Materialprüfungsanstalten, Sonderheft 20, Julius Springer, Berlin, 1932.

[24] M. Gensamer, "Statie Crack Strength of Metals, Its Determination and Significance," *Metal Progress*, Vol. 38, 1940, pp. 58–64.

[25] D. J. McAdam, Jr., "The Technical Cohesive Strength of Metals," *Journal of Applied Mechanics, Trans. A. S. M. E.*, Vol. 63, 1941, pp. A155–165. "The Technical Cohesive Strength and Yield Strength of Metals," *A. I. M. E. Technical Publication No. 1414, Metals Technology*, January, 1942.

[26] D. J. McAdam, Jr., and R. W. Mebs, "An Investigation of the Technical Cohesive Strength of Metals," *Metals Technology*, August, 1943, pp. 1–63.

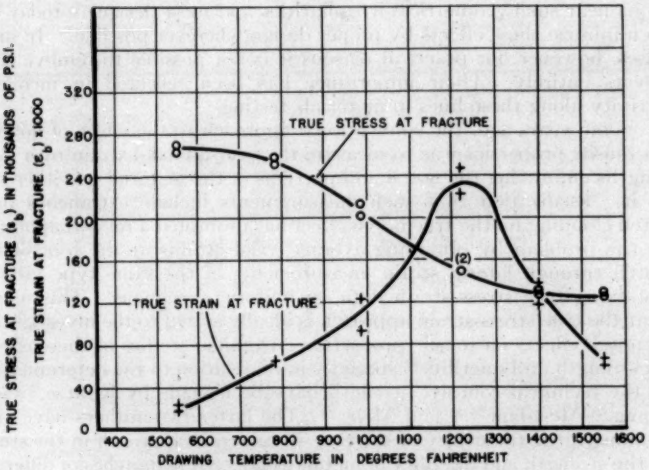

FIG. 23 AVERAGE TRUE STRESS AT FRACTURE (S_b) AND TRUE STRAIN AT FRACTURE (ϵ_b) FROM NOTCHED TENSION TESTS ON QUENCHED AND DRAWN SAE 1045 STEEL AS A FUNCTION OF DRAWING TEMPERATURE.

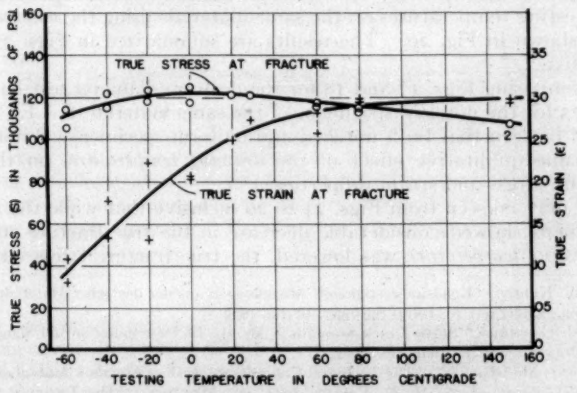

FIG. 24 AVERAGE TRUE FRACTURE STRESS (S_b) AND TRUE FRACTURE STRAIN (ϵ_b) FROM RAPID NOTCHED TENSION TESTS ON ANNEALED SAE 1020 STEEL AS AFFECTED BY TESTING TEMPERATURE.

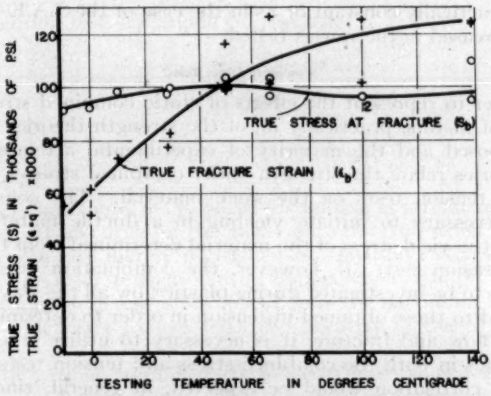
TRUE STRESS (S) IN THOUSANDS OF PSI
TRUE STRAIN (ε') x1000
TRUE STRESS AT FRACTURE (S_b)
TRUE FRACTURE STRAIN (ε_b)
TESTING TEMPERATURE IN DEGREES CENTIGRADE

FIG. 25 AVERAGE TRUE FRACTURE STRESS (S_b) AND TRUE FRACTURE STRAIN (ϵ_b) AS FUNCTIONS OF TESTING TEMPERATURE DETERMINED FROM RAPID NOTCHED TENSION TESTS ON ANNEALED SAE 1112 STEEL

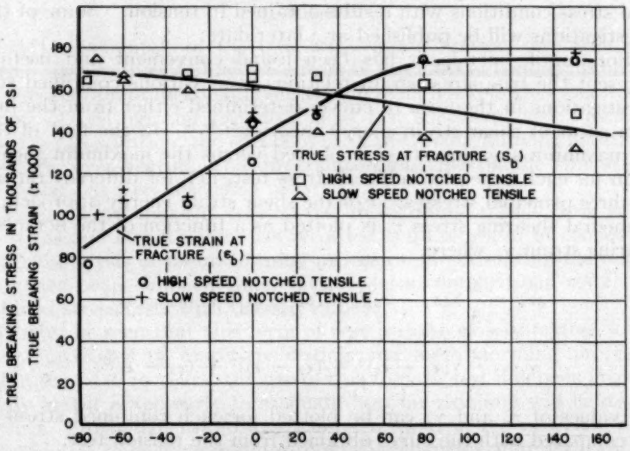
TRUE BREAKING STRESS IN THOUSANDS OF PSI
TRUE BREAKING STRAIN (x 1000)
TRUE STRESS AT FRACTURE (S_b)
HIGH SPEED NOTCHED TENSILE
SLOW SPEED NOTCHED TENSILE
TRUE STRAIN AT FRACTURE (ε_b)
HIGH SPEED NOTCHED TENSILE
SLOW SPEED NOTCHED TENSILE
TESTING TEMPERATURE IN DEGREES CENTIGRADE

FIG. 26 THE EFFECT OF TESTING TEMPERATURE ON THE AVERAGE TRUE FRACTURE STRESS (S_b) AND THE TRUE FRACTURE STRAIN (ϵ_b) AS DETERMINED BY NOTCHED TENSION TESTS ON ANNEALED SAE 3140 STEEL.

mained practically constant or as in the case of the S.A.E.—3140 steel slowly increased in the ranges tested.

Combined Stress Tests.

In order to represent the effects of static combined stresses on the strength of metals, practically all of the strength theories which have been proposed and the majority of experimental attempts to verify these theories relate the strength under combined stresses to that obtained in tension tests on the same material. The combination of stresses necessary to initiate yielding in a ductile material may be related to the yield stress of the material determined from the ordinary form of tension test. If, however, the combination of stresses and strains are to be investigated during plastic flow all the way to fracture and related to those obtained in tension in order to determine the laws of plastic flow and fracture, it is necessary to utilize true stress and strain values in both the combined stress and tension tests. Without this, little correlation would be expected, in general, since fictitious values in both tests would be thus employed.

This indicates that the true stress-strain tension test has a rather vital place in combined stress investigations. It has been used in connection with various combined stress tests in our laboratories in order to compare the strength and ductility of metals under different multiaxial stress conditions with results obtained in tension. Some of these investigations will be published at a later date.

For ductile metals, it has been found convenient and useful to represent the true stress-strain relations from various combined stress investigations in the form of curves determined either from the maximum shear or shear strain energy theories.[27,28,10] In the first of these the maximum shearing stress is plotted versus the maximum shearing strain for each type of combined stress test, i.e., for different ratios of the three principal stresses. For the shear strain energy approach, the octahedral shearing stress τ_n is plotted as a function of the octahedral shearing strain γ_n where

$$\tau_n = \frac{1}{3}\sqrt{(s_1 - s_2)^2 + (s_2 - s_3)^2 + (s_3 - s_1)^2}$$
$$\gamma_n = \frac{2}{3}\sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2}. \qquad (12)$$

The values of τ_n and γ_n can be plotted for each combined stress test and compared with the curve obtained from the tension test.

[27] A. Nadai, "Plastic Behavior of Metals in the Strain-Hardening Range, Part I," *Journal of Applied Physics*, March, 1937, pp. 205–213. E. A. Davis, Part II, same Journal, pp. 213–217.

[28] C. W. MacGregor and J. A. Hrones, "Recent Investigations in Plastic Torsion," *Journal of Applied Mechanics*, December 1937.

For the tension test, equations (12) become

$$\tau_n = \frac{\sqrt{2}}{3} \cdot S = \frac{\sqrt{2}}{3} \cdot \frac{P}{A}$$
$$\gamma_n = \sqrt{2} \cdot \epsilon = \sqrt{2} \cdot \log_e \frac{A_0}{A}. \tag{13}$$

It is thus seen that the $\tau_n - \gamma_n$ curve for tension is similar in shape to the true stress-strain curve for the metal since the true stress S and the true strain $\epsilon = q'$ are merely multiplied by constant factors. Hence, the $\tau_n - \gamma_n$ curve for tension can be obtained very simply from the true stress-strain curve and is also linear from the maximum load point to fracture; which fact follows from the linearity of the $S - \epsilon$ curve in this range.

Tests with various combined stress ratios have shown that up to the maximum load point, the $\tau_n - \gamma_n$ curves for many metals are fairly close together, but depart more and more as the fracture point is approached. If the strains are not too large, a fundamental stress-strain curve is thus obtained for ductile metals independent of the stress combination.

IX. SUMMARY.

The fundamentals of the true stress-strain tension test were presented. Its use in revealing the effects of mechanical conditions on the true stress-strain properties of metals such as high and low temperatures, velocity of testing, and proportions of test specimen were described (Part I). In addition, the effects of heat-treatment, alloying additions, cold-work, over-heating, and directional properties on the true stress-strain relations were discussed (Part II).

It was shown that the tension test in its more rational form where true stress and strain values are recorded is quite useful in connection with the analysis of metal forming processes, in correlating the results of notched-beam impact tests, fatigue tests, notched-bar tests, and combined stress tests with tension values.

It may be seen that this form of test is quite closely related to the general problems of materials testing and metal forming processes. Within the past 10 years, the use of this form of test has been growing rapidly and it is too early to estimate how far reaching will be its significance. Although its growth has been rapid in recent years, more work remains to be done in order to reveal new fields of application and to improve our knowledge of the test itself. We have a wealth of background surrounding the standard routine test carried out over many years. If this paper will stimulate others to carry out research on this problem, it will have achieved its purpose.

X. ACKNOWLEDGMENT.

The research work described herein would not have been possible except for the friendly interest, support and assistance given to the author by various members of the administration, staff, and students at the Massachusetts Institute of Technology. In particular, he would like to acknowledge the interest and support of Dr. Compton, and Dr. Hunsaker. Valuable assistance in the various investigations carried out at different times during the past 10 years was received from P. R. Shepler, L. F. Coffin, Jr., J. C. Fisher, J. A. Hrones, F. J. Mehringer, L. E. Welch, A. H. Prucknicki, and others. The careful machining of specimens and the construction of apparatus was performed by F. W. Perkins and H. B. Johnson.

THE RETENTION OF FLUIDS BY SOLIDS.

BY

P. G. NUTTING.

The amount of fluid associated with a solid increases or decreases until equilibrium with its surroundings is reached. The associated fluid is retained with an energy or cohesive pressure greater than if the solid were not present. To interpret and predict the behavior of solids on drying, it is necessary to develop a theory of drying which gives a relation between the amount of retained fluid at any temperature and pressure and the energy necessary to transfer it to the free vapor phase.

The literature of surface chemistry and physics includes many attempts to construct a theory of adsorption but these contain so many limiting assumptions that they are useful only in narrow fields. The thermodynamics of dilute solutions is treated at length in many texts but concentrated solutions and moist solids are given scant attention. When vapor pressures depend upon the *amount* of fluid present in the condensed phase, evidently a new theory going back to fundamentals is required. A method for doing this is here presented. The relations found are simple and easily applied but have been concealed in a tangle of assumptions and approximations.

As shown by Gibbs, a body is in equilibrium with its surroundings when the differential of its thermodynamic potential, $U - TS + pv$, is zero. No chemical changes are concerned in the present problem. Hence

$$(dU - TdS + pdv) - SdT + vdp = 0. \tag{1}$$

That portion of this derivative included in the parenthesis is by itself zero so that the working equation for this class of problems is simply

$$SdT = vdp \tag{2}$$

which applies to both the condensed (adsorbed) and the vapor phase.

Since entropy $S = H/T$ is the ratio of thermal energy H to absolute temperature T, a change of state involves the thermal energy $H' - H = (S' - S)T = L$ and from (2)

$$L = (v' - v)Tdp/dT \tag{3}$$

the primes referring to the vapor phase. This is the celebrated Clausius equation. In it, $Tdp/dT = ST/v$, the "Clapeyron factor," is simply thermal energy density.

The Clausius equation (3) is exact. It may be noted that two celebrated and much used relations follow directly from it if v' is so much larger than v that v/v' may be neglected. Dividing through by $pv' = RT$

$$\frac{L}{RT} = \left(1 - \frac{v}{v'}\right)\frac{d \log p}{d \log T}, \tag{4}$$

when $v:v'$ is negligible in comparison with unity, (4) becomes simply

$$\frac{d \log p}{d \log T} = \frac{L}{RT}. \tag{5}$$

This is the celebrated Le Chatelier equation usually written $d \log p/dT = -L/RT^2$. If the mass law constant K is written for p in (5) it becomes the well known Van't Hoff equation. Neither of these relations can be expected to hold except for dilute solutions without the volume correction indicated in (3) and (4). Incidentally the Thomson equation $dT/dp = T\alpha v/C_p$, for the change of temperature produced by deformation, may be derived directly from the simple Gibbs relation (2) by expressing entropy in terms of heat and change of volume in terms of the coefficient of expansion α. In this case no change of phase is involved.

For isolated fluids relation (3) is used in differential form. This equation cannot be integrated since the specific volumes v and v' cannot be expressed in terms of p and T and both are variable. With one class of adsorption data these specific volumes are constant and (3) or (4) integrate into $\log p = A - B/T$. In case the volume correction is negligible (5) integrates into

$$\log (p_0/p) = L/RT \tag{6}$$

so that $L = RB$ in this case, or $L = RT(\log p_0 - \log p)$. The Trouton constant, Duhring's rule, Othmer's diagram and many similar relations are forms of (6) which assume p_0 to be a universal constant. It is nearly so even for such diverse substances as mercury, hydrogen and water.

Experimental data, to be interpreted through the fundamental relations derived above, are of three different classes; heat of wetting, change of weight with temperature, and change of weight with vapor pressure as outlined below.

1. *Heat of Wetting.* The solid material, preferably in powder form to give it a larger surface and therefore produce a larger temperature change, is first brought to constant weight in an atmosphere containing the retained fluid at a known temperature and pressure then plunged into the liquid in a calorimeter and the rise in temperature noted. The heat released is chiefly of two different origins; that due to the build

up of the adsorbed film and that due to the release of surface energy by decrease of the fluid surface from its large value in the powdered solid to practically zero in the immersed state. Data on the heat of wetting of silica were collected and interpreted by the writer.[1] By immersing a powder first brought to equilibrium with saturated water vapor, Harkins and Jura [2] have deduced its total surface area (heat of wetting divided by surface energy). Heats of wetting amount to but a few calories, hence the method although simple and direct, is incapable of high precision and it is applicable only in the lower range of temperatures.

2. *Weight-Temperature Data.* The solid is brought to constant weight at a series of known temperatures with vapor pressure constant for each series. If the temperature steps are small (50° or less), such data plot in a smooth graph. If minerals are ground to 150 mesh (0.1 mm.), hydrates reach constant weight in 24 hours or less, carbonates require a month or six weeks at points near the break down temperature. Too fine grinding (ball milling) lowers and rounds off the shoulders of the weight-temperature curve.

The graphed data then show the retention at each temperature per gram of anhydrous solid. The above theory gives the energy required to vaporize the liquid at each temperature and pressure. From these two sets of data therefore the energy of vaporization is given directly as a function of retention which is the relation sought. This method gives results of considerable precision and with a theoretical foundation, promises great usefulness in research and engineering. The writer has obtained upwards of 360 weight-temperature curves in the past 15 years of which 73 were selected for publication in Prof. Paper 197-E of the U. S. Geological Survey in 1943.

3. *Retention-Vapor Pressure Data.* Specimens are placed in closed vessels containing sulphuric acid of a series of known concentrations and having vapor pressures 0, 0.05, . . . 1.0 of saturation and left to attain constant weight, usually about two weeks, then advanced to the next higher vapor pressure. This series of weights graphed give vapor pressure as a function of retention. Theory gives a relation between energy and vapor pressure so that energy as a function of retention is at once obtainable.

This method is fairly precise but very slow and it has been used only for exploratory work. Shorter methods have been devised but unless full equilibrium is attained at every point the results are of little service. However even approximate values of the *rate* of drying, through small ranges of intermediate temperatures and relative humidities, are of very great industrial significance. The simple relation

[1] "The adsorptive force of silica for water," *J. Phys. Chem.*, April 1927.

[2] Harkins and Jura, *J. Chem. Physics*, Sept. 1943.

(6) here offered is believed adequate for predicting the condition of a moist body at any temperature and pressure when its condition under any standard temperature and pressure are known.

A few special cases are given below to illustrate the application of the general theory to specific problems and bring out the vital points of the method.

With weight-temperature data on retention, p is the constant pressure of say water vapor of the room, usually about 15 mm. or 19980 dynes/cm.^{2} of which the natural log is 9.9025. The value of log p_0 (found from the heat of vaporization of pure water when its vapor pressure is 15 mm.) is 28.253. Therefore for this class of problems (p constant, T variable) the energy required for a transfer from retained to vapor phase is given by

$$L = 18.35RT. \tag{7}$$

For example, the water leaving a mineral heated to 110° C. (283.2° K.) requires 760 cal./gm. to drive it off or 760 − 532 = 228 cal./gm. in excess of that required to vaporize free water at that temperature. Both energies include the external latent heat RT (= 41.4 cal./gm. at 110°). If desired (7) may be written $L = 17.35RT$ for the internal energy of association which is 491 cal./gm. for free water. For any constant vapor pressure, the energy of retention L is proportional to the absolute temperature. Above the critical temperature (374.15° C. for water) there is no correction for free water but the relation appears to hold even for water released as H and OH ions. For high temperature catalysts the formula should be applicable when pressures and temperatures are known.

TABLE I.

Energy and Water Retention of Deweylite.

T	t	R	E	T	t	R	E
303	30	.171	613	793	520	.1270	1604
338	65	.159	684	823	550	.0950	1665
373	100	.1565	754	833	560	.0540	1685
473	200	.1508	957	843	570	.0270	1705
573	300	.1451	1159	923	650	.0154	1867
673	400	.1394	1361	1023	750	.0088	2069
753	480	.1350	1523	1123	850	.0025	2272
				1173	900	.0000	2373

The weight-temperature curve for deweylite (a variety of serpentine) has been selected to illustrate the reduction of data. Deweylite contains about 17 per cent. water ($3H_2O$) under room conditions and its thermal curve well shows all three of the usual types of water release. Ordinary drying (reversible water) ceases at about 90°. $2H_2O$ is lost

abruptly at about 550° C., evidently a hydrate, breaking down when the internal thermal energy reaches 1650–1700 cal./gm. From 90 to 480° and from 650 to 900° (above which there is no further change) the weight is a linear function of temperature, about .0057 per cent./deg. The nature of this loss of water is not yet known. It is remarkable in its uniformity and in being independent of the dehydration break at 550°. Data are given in Table 1, and figure 1. At each temperature,

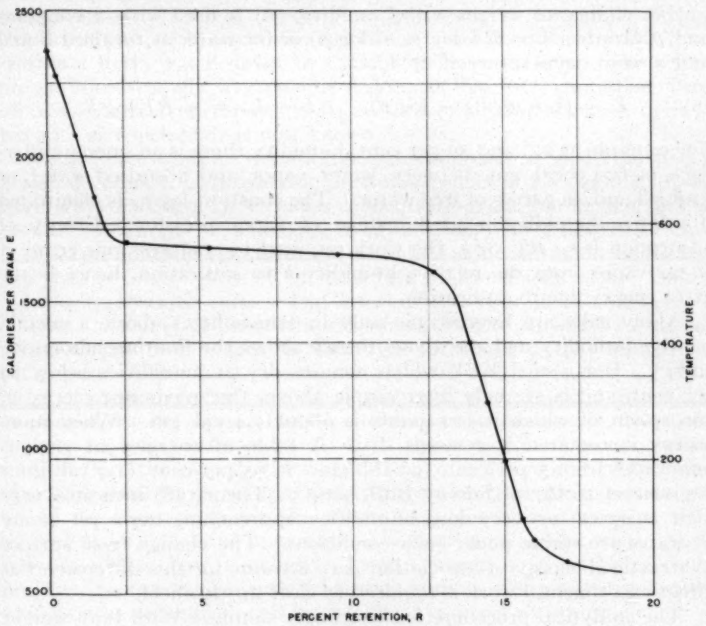

FIG. 1. Showing the variation in the heat of vaporization of the retained water with the amount of water remaining for the serpentine mineral deweylite ground to 0.1 mm and brought to constant weight at each temperature. The removal of the last water at 900° requires about 2370 cal./gram.

the retention R is in grams of water in each gram of anhydrous (900°) mineral. At that temperature water requires E calories per gram to transfer it to the vapor phase as computed from (7).

The linear portions of the energy curve (Fig. 1) have definite slopes indicating a progressive increase in energy of retention with decrease in the amount of retention. This is not an edge effect due to fine grinding

which merely rounds off shoulders and elbows of such curves. It has been suggested by R. E. Stevens that the loss of the first few H and OH ions from the lattice may increase the strength of the residual electric field so that the last ions require more thermal energy to drive them off. Kaolinite, pyrophyllite and some micas lose little weight out to the chief dehydration drop but the montmorillonite minerals and many other hydrates give curves having decided linear slopes. The effect is too uniform over too wide a range to be merely a depth effect.

For change of weight with humidity, (6) is used with T constant and p variable, $L = RT(\log p_0 - \log p)$ or for water as retained liquid and a room temperature of 27° C.

$$(8) \qquad L = 33.0(28.783 - \log p), \qquad L - L_w = -RT \log h.$$

For example at 27° and 50 per cent. humidity there is an energy difference of 604.0 cal./gm. between water vapor and adsorbed water or 22.8 cal./gm. in excess of free water. The constant $\log p_0$ is eliminated if relative humidity is used instead of vapor pressure. Energy of adsorption is $-RT \log h$, the work required to compress one gram of water vapor from the relative humidity h to saturation, hence is the extra energy due to adsorption.

Many salts are hygroscopic only in atmospheres above a certain relative humidity and the above theory shows the limiting adsorptive energy. For a salt (KCl) which remains dry at humidities below 80 per cent. and is strongly hygroscopic above, the maximum energy of adsorption of which it is capable is about 7.4 cal./gm. When more energy is required it remains dry. A table of energies at various humidities from 5 per cent. (99 cal./gm.) to 95 per cent. (1.7 cal./gm.) is given on p. 167 of Survey Bull. 928-C. Theory (8) indicates very high energies for very low humidities approaching zero yet many hydrates are stable under such conditions. The change from surface to structural energy of association may account for this difference but direct experimental work is required to clear up this field.

The analytical procedure is exceedingly simple. With both weight (experimental) and energy (by 8) given as functions of vapor pressure or relative humidity, energy is graphed as a function of water content or retention. Available data on clays is given in reference 1 and in Bull. 928-C, on zinc chloride solutions by G. S. Kasbekar [3] (given in *Chem. Abs.* **35**, 5771). The energy of retention ranges from nothing in saturated air to 99 cal./gram at 5 per cent. relative humidity. That energy drops sharply as retention increases from zero up to about 10 per cent. for clays, then very slowly up to the value at saturation, about 45–50 per cent. for bentonite clays. These initial and final

[3] G. S. Kasbekar, *J. Ind. Chem. Soc.* **17**, 657–662, 1940.

slopes are evidently adsorption effects differing radically in their nature. An inner adsorption of H and OH ions followed by a van der Waals adsorption as H_2O would account for the abrupt break between widely different slopes as suggested by the writer in 1927 (reference 1).

Maintaining a desired fixed humidity in a closed space by means of solutions of salts or sulphuric acid has been common practice for many years. A slice of raw apple in a tobacco jar is a familiar example. With continued loss of water vapor pressure drops until the work of condensation ($RT \log h$) is equal to the energy of retention. Below this critical vapor pressure the substance either becomes dry (KCl) or retains a little water down to extremely low pressures. The vapor pressures of strongly hygroscopic disiccants like P_2O_5 containing very small amounts of water would be an interesting and valuable field of research of which little is now known.

With dilute solutions retention energies approach zero and the theory is well developed. For osmotic pressure, instead of $RT \log h$ in (8) we have $pv_0 = RT$ log relative molar concentration, another form of Gibbs' chemical potential. A substance in equilibrium with saturated air may (1) contain no water (paraffin), (2) contain a moderate amount of water like the bentonitic clays or (3) be dilute solutions such as are formed by the hygroscopic salts. The intermediate type is of considerable interest. A lump of bentonitic clay fresh from a pit usually contains about 60 per cent. water, in saturated air about 45 per cent., over P_2O_5 about 10 per cent., removable only by heating to 600° C. If a lump of room dry clay (say 20–25 per cent. water) and a thin water suspension of the same clay be enclosed in saturated air, both will come to the same water content (about 46 per cent.). The suspension. so thin that the clay settles out leaving a millimeter of clear water above it, must have a vapor pressure greater than saturation to get rid of the excess water. The writer has done this experiment with several clays. Gelatin apparently behaves in a similar way. It is difficult to see how a cohesive force between solid particles could produce the excess of kinetic (thermal) motion of the water molecules necessary to accomplish this drying effect in water saturated air.

The gradient of energy (or pressure) through an adsorbed film must depend upon the molecular nature of the fluid adsorbed but there is no apparent basis for the common assumption that it increases (inward) by the internal latent heat with each molecular layer. This gradient 100 is times the value found by the writer for even the inner layers of water adsorbed on silica (reference 1). The outer layer must be in equilibrium with the environment while the innermost layer may be adsorbed with energies varying from nothing up to a very large value (valence adsorption). It is a promising field of research to determine how intermediate gradients vary with the solid and with the fluid retained by it.

SUMMARY.

A general relation between energy of retention, pressure and temperature has been developed by thermodynamic methods, applicable even to cases where that energy varies with the amount of fluid present.

The three classes of experimental data on adsorption are reviewed, their interpretation in the light of thermodynamic theory is discussed and relations between energy of change of phase and amount of fluid retained are deduced.

Research necessary to clear up the whole field of fluid retention by solids from pure liquid to pure solid is indicated.

RAY LENGTH IN SANITARY VENTILATION BY BACTERICIDAL IRRADIATION OF AIR.

BY

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Elementary physical factors governing the bactericidal irradiation of air [1] were formulated in the first part of this study on sanitary ventilation by radiant disinfection. The formulations have been applied to surgical air asepsis,[2] ward isolation by corridor barriers,[3] cubicle isolation by light curtains,[4] prevention of cross infection in nurseries,[5] and the environmental control of the epidemic spread of contagion among school children.[6] Bacteriological and epidemiological data can now be correlated with physical factors.[7]

RADIATION.

An attempt is made here to derive from theory the practical import of ray length in sanitary ventilation by radiant disinfection. It is assumed that the bactericidal power of photons radiated into a confined atmosphere, within which air-suspended particles constitute a negligible volume, varies with the distance traversed between the points of origin and disappearance of the rays. If intensity of irradiation is represented by a hypothetical number of photons (radiant energy) intercepting unit area in unit time, then the summed products of the photons by ray lengths, divided by volume of the enclosed space, defines average intensity.

BACTERICIDAL IRRADIATION.

The number of air-suspended bacteria killed by irradiation of a dry confined atmosphere can theoretically be deduced from a generalized hypothesis combining three accepted laws: [1] the inverse square law of radiant intensity; the Roscoe-Bunsen law of reciprocity of time and intensity of exposure; and the logarithmic law of disinfection. By this hypothesis the number killed becomes proportional to the number of photons (radiant energy) intercepted by living bacteria.[8] The relations derived from the hypothesis have been experimentally verified under laboratory conditions [9] and should help to interpret data collected in practical air disinfection,[7] although theory unfortunately cannot com-

* Supported by a grant from the Commonwealth Fund to the University of Pennsylvania for the study of the prevention and control of air-borne infection.

pensate for faulty measurement of irradiation and disinfection or inadequate data on ventilation and epidemiology.

EFFICIENCY OF IRRADIATION.

Consider first a square classroom of about 6,000 cubic feet capacity, indirectly irradiated by a fixture suspended four feet below the center of an eleven-foot ceiling (Chart I). The solid angles (W), subtended in

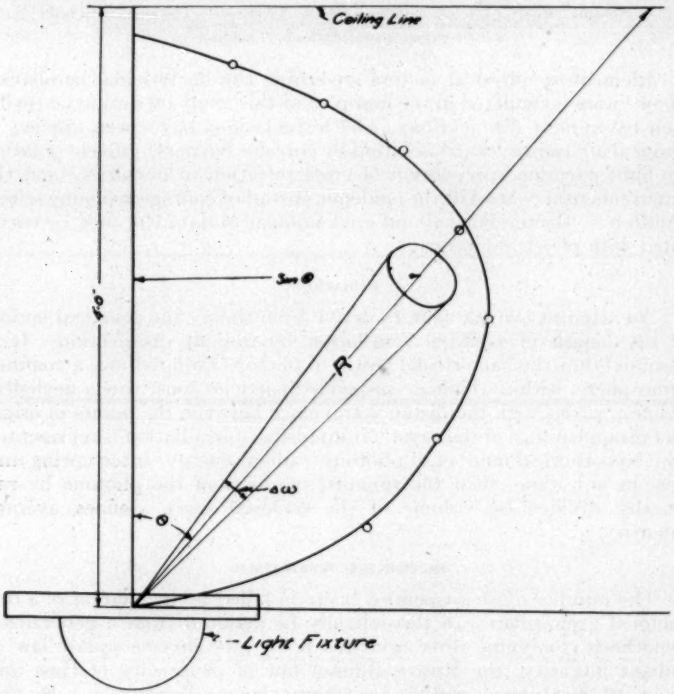

CHART I. Distribution curve of solid angular flux density from hanging central fixture (assuming point source).

conical wedges between angles ($\theta_a - \theta_b$) from a vertical axis, indicated in the first column of Table I, are given in the second column. Approximate average angular radiant flux densities (I) as determined within each wedge by a photometer, are given in the third column; radiant flux (IW) in the fourth; average ray length (R) from the source

TABLE I.
Irradiation Efficiency.

Between Cones.	Solid Angle (Steradians).	Radiant Flux Density (Watts per Steradian).	Radiant Flux (Watts).	Ray Length (Feet).	Irradiation (Foot-watts).
$\theta_a - \theta_b$	W	I	IW	R	IWR
0°–5°	.031	.315	.010	4.00	.040
5°–15°	.190	.304	.057	4.04	.230
15°–25°	.376	.295	.111	4.25	.450
25°–35°	.550	.290	.160	4.62	.740
35°–45°	.707	.272	.193	5.25	1.000
45°–55°	.843	.249	.208	6.20	1.290
55°–65°	.953	.189	.180	8.00	1.440
65°–75°	1.034	.135	.140	11.68	1.640
75°–85°	1.084	.064	.070	12.00	.840

Total Irradiation in foot-watts = $\Sigma IWR = 7.670$

Room Volume = $V_0 = 6000$ cubic feet
Average Intensity = $\bar{E} = \Sigma IWR/V_0 = 1.28$ milliwatts/sq. ft.
Total Flux (lamp rating) = $F_0 = 2$ watts
Mean Ray Length = $\bar{R} = \Sigma IWR/F_0 = 3.8$ feet
Uniform Cubic Flux Density = $E_u = F_0 V_0^{\frac{1}{3}} = 6.06$ milliwatts/sq. ft.
Irradiation Efficiency = $\bar{E}/E_u = 21$ per cent.
(1.1 milliwatts/ft.^{2} = microwatts/cm.^{2})

to the ceiling (extended if necessary) in the fifth; and irradiation (IWR) in the sixth. Total irradiation (ΣIWR) in the last column gives, in a room of 6,000 cubic feet volume (V_0), an average intensity ($\bar{E} = \Sigma IWR/V_0$) of 1.28 milliwatts per square foot, and with lamps rated at 2 watts (F_0) mean ray length ($\bar{R} = \Sigma IWR/F_0$) becomes 3.8 feet. Since the theoretically maximum intensity in a cube of 6,000 cubic feet, uniformly irradiated with 2 watts ($E_u = F_0\sqrt[3]{V_0}/V_0 = F_0 V_0^{\frac{1}{3}}$) is 6.06 milliwatts per square foot,[10] the per cent. actually realized ($\bar{E}/E_u =$ 21 per cent.) might be called the Efficiency of Irradiation.

For a second example, consider a rectangular schoolroom of about 7,000 cubic feet capacity having the same ceiling height and irradiated by two fixtures on each end wall at seven-foot level. The reflectors throw a beam indicated on Chart II by a butterfly-wing distribution curve of angular flux density measured in a plane normal to the center of the tube. The elevation of this beam can be varied by rotating the fixture without altering distribution of radiation about the beam axis. Lengthening the rays by lowering the beam axis from 60° to 25° from horizontal increased efficiency of irradiation from 19 to 57 per cent. without altering the light, the fixture or position of the fixture in the room.[11]

This example illustrates the importance of design in converting radiation into irradiation. By attaching a visor to the lower edge of the reflector, the beam was lowered without erythemal exposure of the

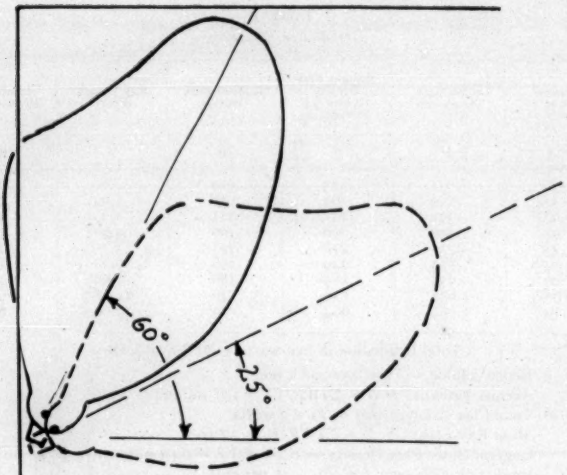

CHART II. Distribution curve of solid angular flux density in plane normal to center of wall fixture showing shortening of ray length with elevation of beam.

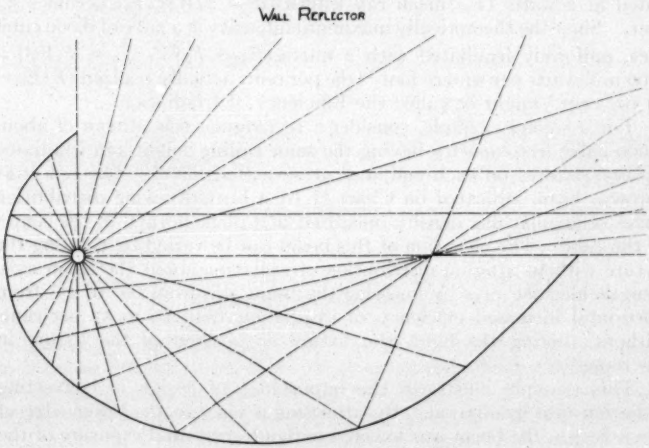

CHART III. Geometry of effective wall fixture.

occupants, and the increase in ray length even with sacrifice of radiant flux, doubled irradiation. The geometric ideal illustrated in Chart III is approached in wall fixtures now available.

EFFICIENCY OF DISINFECTION.

The dilution of vitiated air by ventilation is customarily expressed as room volumes of fresh air—called air-changes or overturns. An air-

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change can be shown by the logarithmic law of dilution to remove 63.2 per cent. of the initial contamination. In measuring sanitary ventilation by air disinfection, therefore, the lethal disposal of 63.2 per cent. of a standard suspension of test organisms, called a *lethe* (L), becomes the sanitary equivalent of an air-change; and because of identical laws, the dilution by a given number of cubic feet of fresh air in ventilation equals bacterial disposal by the same number of *foot lethes* (LV_0) of disinfection in sanitary ventilation.

It follows from the generalized law that the maximum rate of disinfection occurs when living organisms are uniformly exposed to irradiation, either because of uniform density of survivors, or intensity of irradiation. The uniform irradiation of ventilating volumes is ex-

tremely difficult but, as uniformity of exposure was approached, a thousand *foot lethes* of disinfection appeared from early experiments [1] to approach a foot-watt-minute of irradiation. In the absence of an absolute evaluation either of the lethal equivalent of radiant energy or of average disinfection, this value of the maximum was adopted in computations. More recent determinations indicate a maximum of half this value, but since the maximum theoretical intensity of irradiation is also double that ordinarily obtainable from artificial sources within enclosed spaces,[10] the ratio of *foot lethes* bacteriologically determined, to

Germantown Friends School, Philadelphia, Pennsylvania.

computed foot watt minutes, remains a useful comparative index of the Efficiency of Disinfection.

With non-uniform irradiation the different rates of disinfection lead to density gradients of surviving bacteria which lower average exposure to average intensity. Uniformity of irradiation of organisms in a relatively fixed position, because of slow mixing compared to disinfection rate, is indicated by high efficiency of disinfection, and since within an enclosed space the paths of photons cannot very well be lengthened without distributing irradiation more uniformly, efficiency of irradiation becomes a factor in efficiency of disinfection.

Bacterial densities are, however, being continuously equalized by ventilation currents, and the more rapidly air is circulated the closer will the average approach the maximum rate of disinfection under uniform exposure to average intensity. The role of air circulation in radiant disinfection is well illustrated by the limiting case of irradiation of recirculated air, where *foot lethes* of disinfection approach cubic feet of recirculation as percentage removal in the duct approaches a hundred per cent.[10] Internal circulation of air masses within a room performs a similar role, but here the relative disposition of differently irradiated regions is quite as important as air motion. With constant distribution of irradiation, differences in efficiency of disinfection are due to differences in circulation. With constant circulation, the effect of mixing increases with wider distribution of irradiation, and is related therefore to efficiency of irradiation. Thus the effect of ray length is compounded three ways in radiant disinfection of air.

Lethal change is measured bacteriologically [12] by determining the disposal rate of test organisms atomized into the atmosphere. The dependence of disinfection upon irradiation efficiency was clearly demonstrated in the second example, where disinfection efficiencies of 19.2 and 57.5 per cent. were almost identical with irradiation efficiencies. The direct proportionality between the latter and ray length follows from definition, but in the former is quite coincidental, for low irradiation efficiency in the first example yielded high disinfection efficiency—63 per cent. The more effective utilization of circulation by irradiation of the core rather than the stagnant corners of the room, together with relative increase in circulation due to lower disinfection rate, is confirmed by the lesser bacterial gradients between different sampling stations as shown by a coefficient of variability of 41 per cent. as compared with 71 per cent.

The products of irradiation and disinfection efficiencies, 13 per cent. in the first example, and 4 per cent. in the second example with high and 37 per cent. with low beam angle, measure over all efficiencies of radiant disinfection of air. The compounding of efficiency factors by direct irradiation is well illustrated in the second example. Thus in an operating room, where two diagonal beams, from angles formed by the twelve-foot ceiling and side walls, cross at the operating site, bacteriologic tests indicate an efficiency approximating that of uniform intensity.[2] The steepness of the angle, distance from the source, and shade from the operating light, protect the eyes and skin of the operating team from erythemal exposure during an operating period.

BARRIER EFFICIENCY.

The quantitative determination at any point, of the atmospheric concentration of organisms contributed to the atmosphere at some other point, bacteriologically integrates factors of air-borne infection between

the two points. A change in atmospheric concentration due to air disinfection therefore measures the protection afforded a person at the first point against air-borne infection by another person at the second point. For example, the lethal reduction of concentration of air suspended organisms passing on air currents through a light barrier measures protection against droplet nuclei cross-infection from a patient isolated in a cubicle. In this limiting case the protection given by the barrier is practically proportional to the radiant flux per unit length of curtain, compared to which average disinfection in the room may be insignificant.[13] Blockade of normal channels of spread of infection, by concentrated irradiation, affords greater than average disinfection protection to occupants.

In general, however, the concentration of light in regions away from the occupants will result in less removal of organisms en route from person to person than by average disinfection in the room. The more uniformly organisms are exposed, the more nearly will barrier protection approach average disinfection. The actual protection of pupils, against the spread of certain childhood contagions, was found in the first example to be greater than with double the average disinfection from an elevated beam in the second example.[7] Thus as the efficiency of radiant disinfection of air was raised from 4 to 13 per cent. by good design the hygienic rating of disinfection was almost proportionately increased—a fourth way in which ray length contributes to sanitary ventilation.

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CONCLUSION.

The lengths of bactericidal rays within an enclosed atmosphere may contribute in four ways to sanitary ventilation.

1. The amount of irradiation realized from a radiant source within an enclosed space depends directly upon mean ray length.
2. The uniformity of irradiation of the space normally increases with mean ray length.
3. The uniformity of exposure depending upon air circulation usually increases as rays are lengthened.
4. The disinfection of organisms en route from occupant to occupant generally approaches average disinfection as rays are lengthened.

The hygienic rating of disinfection thus increases *inter alia* with ray length.

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ARMY AND NAVY NOTES.

Detecting Fire at Sea.—(*Electronics*, Vol. 17, No. 7.) Addition of photoelectric smoke detecting apparatus to the Rich system for detecting smoke by sight and smell provides for ships at sea an automatic fire alarm system comparable in speed and effectiveness to the finest modern installations in buildings.

Air samples from each space protected by the automatic Rich-audio system are drawn through individual pipe lines to the detecting cabinet, usually in the wheelhouse by an exhaust fan. The pipe outlets are positioned in concentrated beams of light that illuminate smoke particles and provide visual detection. The air samples are discharged into the wheelhouse, so that smoke will also be detected by smell when present.

Each pipe line is provided with an automatically controlled solenoid valve that momentarily diverts the air sample to a long tube for photoelectric observation. A light beam is directed through this tube to a photovoltaic cell connected to a meter type relay.

A motor-driven selector switch energizes one valve after another at four-second intervals, and drives a number wheel indicating which line is being diverted at any instant. If no smoke is present, the number changes and another line is diverted for photoelectric inspection. Smoke causes operation of the alarm signals and stops the selector switch so the number remains on the control panel to indicate the source of smoke. Controls can be adjusted to compensate for dust on the lens, mirror or photoelectric cell surface.

R. H. O.

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ON THE GEOMETRY OF COLOR SPACE.

BY

DAVID L. MACADAM.

Communication No. 978 from the Kodak Research Laboratories.

"The positions of objects of sense, and the colors, are probably the only simple notions whose modes of determination form a multiply extended manifold."

Riemann, 1854.

The relations between colors, and the significance of some recent research on color vision, can be explained by using for colors some of the conventional methods of representing "the positions of objects of sense."

Color consists of characteristics of light, light being the aspect of radiant energy of which human observers are aware through the agency of the eye and its associated nervous system. Color is neither purely physical nor purely psychological, but depends upon physical characteristics of radiant energy and upon physiological and psychological functions of human vision. Because of this joint dependence, color is considered to be psychophysical. The most familiar characteristic of light, included in color, is associated with the sensation of brightness and is called luminance.* The other characteristics of light which are included in color correspond to the sensations of hue (for example, red, yellow, green, and purple), and saturation. The characteristics of light which correspond to these attributes of visual sensation can be specified in several alternative ways. It is very difficult, if not impossible, however, to specify characteristics of light which correspond separately to the sensations of hue and saturation under all of the conditions of observation which are commonly encountered. All existing colorimetric methods employ arbitrary schemes for specifying characteristics of light which jointly, but not separately, correspond to the hue and saturation attributes of visual sensation. Some of these characteristics, such as dominant wave length and purity, correspond in a general way with hue and saturation, while other schemes of specification forgo the use of parameters which correlate even roughly with hue and saturation separately, in order to reveal or portray general psychophysical relations between colors. "Chromaticity" is

* In most systems of photometric nomenclature, this quantity is called "brightness," but in order to distinguish it from the corresponding attribute of visual sensation, the Committee on Colorimetry of the Optical Society of America has recommended the use of the name "luminance" for the photometric (psychophysical) quantity. (See reference 1 for more detailed discussion.)

the collective name for the characteristics of light which correspond to the sensations of hue and saturation, irrespective of whether or not the specific pair of characteristics of light shows close correlations with hue and saturation separately. In this paper, chromaticity will be represented by a point in a plane or other surface. The coordinates of the point do not correlate with either hue or saturation, but sensitivities to chromaticity differences of the most general, as well as any desired specific, type can be represented simply and accurately in the resulting diagram.

A diagram on which all chromaticities can be represented is called a "chromaticity diagram." The meaning of the most widely used chromaticity diagram is indicated by Fig. 1. This diagram may be regarded as a map of chromaticities. As in first making acquaintance with geographic maps, little attention need be paid to the coordinate system or to the type of projection used by the map maker. Thus, the coordinates, x and y, in Fig. 1 are analogous to longitude and latitude. The essential meaning and utility of either a map or a chromaticity diagram is shown by the boundaries and neighbors of the several regions represented on the map. Fig. 1 is more nearly analogous to a map of the distribution of languages in Europe than to a map of political domains, since there is a continuous transition of chromaticity throughout each region and across each boundary. The difference in chromaticity represented by the centers of two adjacent regions is on the average neither greater nor less than the difference between chromaticities represented on the two sides of any one region. In the center of the diagram, the unnamed region represents chromaticities which differ so little from daylight that the color name applied to them depends very greatly upon the circumstances under which they are observed. The point labelled "ICI illuminant C" represents the chromaticity of a standard of artificial daylight recommended by the International Commission on Illumination.[2] Light of approximately this quality is frequently called "white," but in deference to a technical reservation of this name for highly reflecting, nonselective surfaces, this term is not assigned to the central region of Fig. 1. Furthermore, the portions of the central region at a considerable distance from the point for ICI illuminant C represent distinct tints, although they are not sufficiently pronounced to be invariably assigned the names shown in the neighboring regions. The convex outer boundary of the named regions represents the chromaticities of spectrum colors, the wave lengths of which are indicated (in millimicrons). The lower limiting boundary of the various red and purple regions represents the purest possible nonspectral colors.

The experimental basis for this chromaticity diagram and for procedures by which colors may be "mapped" with great accuracy upon it need not be discussed here.[3,4] It is important to note, however,

that this diagram represents psychophysical characteristics of radiant energy. Many different spectral distributions of radiant energy are

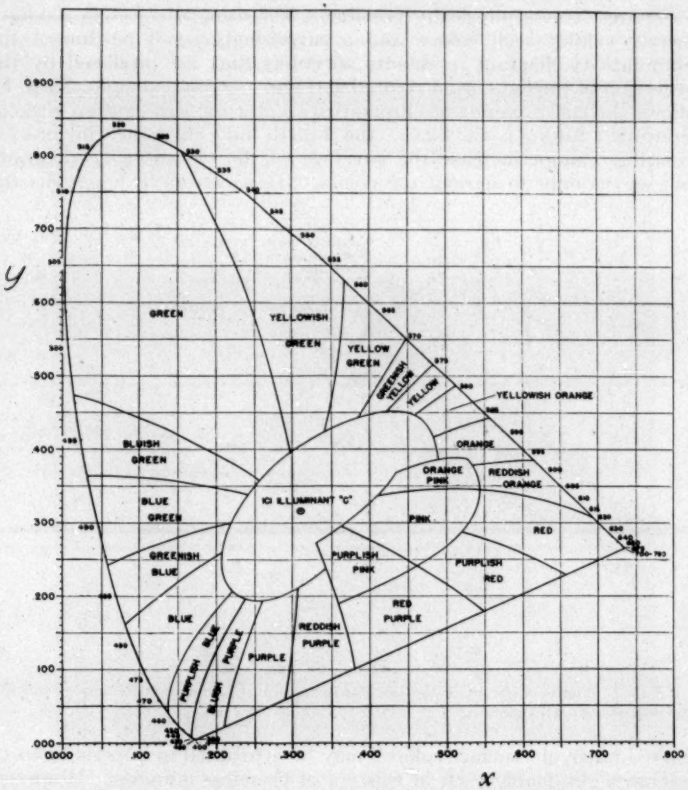

FIG. 1. Suggested definitions of color designations for self-luminous sources. The chromaticities for each designation are indicated on the chromaticity diagram of the standard ICI coordinate system for colorimetry. Spectrum chromaticities are also shown, the wave lengths being indicated in millimicrons. Reprinted by permission from K. L. Kelly, "Color designations for lights," *J. Opt. Soc. Am.*, 1943, **33**: 627–632; also *J. Res. Nat. Bur. Stand.*, 1943, **31**: 271–278 (RP 1565).

represented by any single point in the chromaticity diagram, signifying that they have the same appearance. This corresponds to an outstanding fact of vision, that it is not an analytical sense and that the

various constituents of a color cannot be distinguished as can the components of a musical ensemble.

The outer boundaries of the named regions in Fig. 1 correspond to the purest colors physically possible. Reflecting surfaces in daylight cannot exhibit such colors, and a surprisingly small portion of the chromaticity diagram represents all colors that are produced by the reflection of daylight from colored surfaces. As an example, Plate I * shows the entire gamut of chromaticities of a modern process of color printing. Addition of black, the fourth ink employed in process printing, cannot increase the coverage of the chromaticity diagram, but serves only to darken the colors. To a considerable extent, the

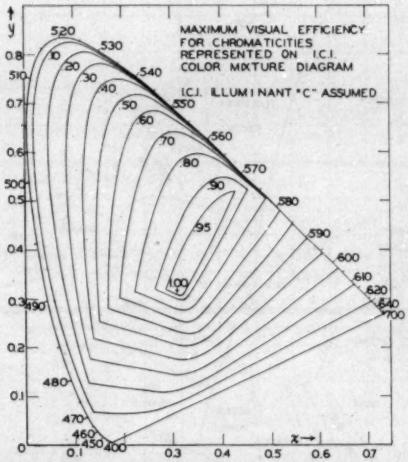

FIG. 2. Limits of chromaticities possible for indicated luminous reflectance of surfaces illuminated with ICI standard "C."

limited range of "surface colors" may be attributed to imperfections of colorants obtainable even in this era of chemical miracles. However, increase of the range of chromaticities by improvement of colorants is ultimately limited by fundamental considerations. Since the color exhibited by any reflecting surface in daylight is a consequence of absorption of some wave lengths, there is an upper limit for the luminous reflectance † of surfaces reflecting light of any specified chromaticity.[5]

* Courtesy of "Life," reprinted from the issue of July 3, 1944.

† "Luminous reflectance" is the ratio of the luminance of a reflecting surface to the luminance of a perfectly reflecting surface, when both are placed in the same completely diffuse illumination.

The maximum possible luminous reflectance for each chromaticity, or conversely, the maximum gamut of chromaticities possible with any specified luminous reflectance, is indicated in Fig. 2. For example, a surface illuminated with ICI standard C, exhibiting the chromaticity represented by $x = 0.43$, $y = 0.27$, cannot possibly have a luminous

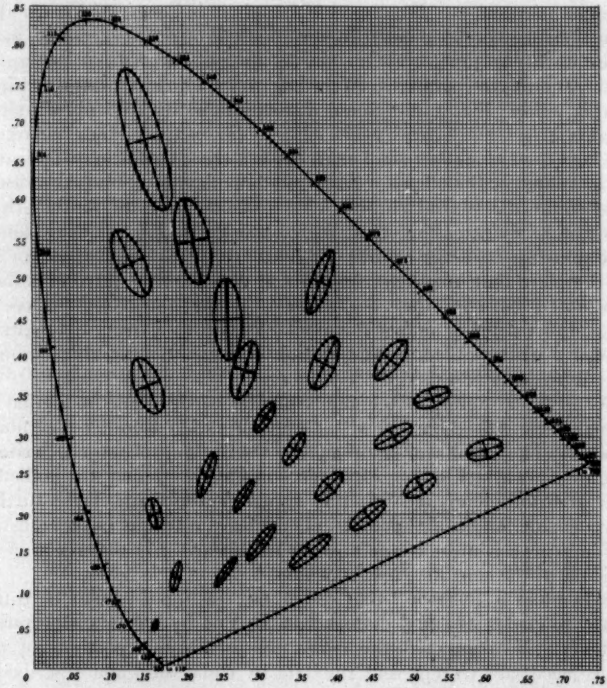

FIG. 3. Standard deviations of visual matches for the chromaticity indicated by the center of each ellipse, represented ten times enlarged on the chromaticity diagram of the standard ICI coordinate system for colorimetry.

reflectance greater than 50 per cent. For technological reasons, these theoretical limits are never equalled and rarely approached by actual colorants. Fig. 2 indicates that chromaticities near the outer boundaries of the named regions of Fig. 1 can be obtained only at considerable sacrifice of luminous reflectance. Colorants known at present permit the attainment of only a small percentage of the gamuts of chromaticities indicated as possible in Fig. 2.

The choice of the coordinate system employed in a chromaticity diagram is a technical matter with which most users of the diagram need not be concerned. It represents an arbitrary convention (in the case of Fig. 1, adopted in 1931 by the International Commission on Illumination: ICI) [2] which, like the choice of a type of projection for a geographic map, governs the sizes and shapes of equivalent figures in different parts of the diagram. Although it is generally known that distortions cannot be avoided by any method of preparing plane maps of the world, the analogous fact in the case of chromaticity diagrams is not generally recognized. According to experimental data obtained by this writer, Fig. 3 represents distortions in the ICI chromaticity diagram. In this figure, each ellipse shows (ten times enlarged) standard deviations of visual matches for the chromaticity indicated by the center of the ellipse. Each radius indicates a possible series of matches for the central chromaticity and one tenth of the length of each radius indicates the standard (or root-mean-square) deviation of these matches from the central chromaticity.[6] Although the data are less complete than might be desired and considerable differences have been noted between the results for different observers,[7,8] there is sufficient consistency among the available data to warrant attempts to develop a distortionless representation of equally noticeable chromaticity differences.[9,10]

As in constructing plane maps of the earth, some reduction of distortion can be accomplished by transformation to other coordinate systems. The results of a projective transformation of the writer's data are shown in Fig. 4. Although considerably reduced, the distortions are not eliminated by this transformation and little further improvement can be obtained in a plane diagram by any other transformation, whether linear (projective) or nonlinear. For discussion of an assertion to the contrary, see Appendix A.

Silberstein has shown [11] that the ellipses in Fig. 3 cannot be transformed to circles of equal diameter in a plane by any transformation whatever. He computed the curvatures of various portions of the surface necessary to represent the data by equal radii and described a method for constructing this surface. A photograph of a crude model of this surface, constructed by the writer, is shown in Fig. 5.* Values

* The procedure employed in constructing this model was as follows:

1. From the ellipses in Fig. 3 values were determined for the metric coefficients, g_{11}, $2g_{12}$, g_{22}, in the equation

$$100 = g_{11}(x - x_0)^2 + 2g_{12}(x - x_0)(y - y_0) + g_{22}(y - y_0)^2$$

where 100 is the square of the magnification (10×) of the ellipses representing the standard deviations in Fig. 3, x, y are the coordinates of any point on an ellipse in Fig. 3, and x_0, y_0 are the coordinates of the center of the same ellipse.

2. Contour maps were drawn, consistent with these values of g_{11}, $2g_{12}$ and g_{22}, representing

of the corresponding coordinates in Figs. 1, 2, and 3 are shown: x to the right and y directly above the appropriate curves on this model. The apparent discontinuity of the $x = 0.40$ locus, especially in the neighborhood of $y = 0.20$, and other less obvious imperfections are indications of the crudity of the model, resulting from the use of the large intervals of x and y indicated in the photograph. Nevertheless, the general appearance of the surface on which the experimental data can be represented by circles of constant radius is clearly indicated. The impossibility of flattening this surface without rupture or distortion is quite evident and the curvatures computed by Silberstein constitute a rigorous proof of this conclusion.[11]

Euclidean three-space is not sufficient for extending the representation of chromaticity shown in Fig. 5, so that equal distances in space represent equally noticeable color differences involving increments of both luminance and chromaticity. For discussion of a proposed Euclidean metric for colors, see Appendix B. The uniform representation of visual sensitivities for combined luminance and chromaticity differences can be expected to require a non-Euclidean three-space, which, in general, cannot be embedded in a Euclidean space of fewer than six dimensions.[11] Construction of a model of such a color space is therefore impossible. Practical problems involving such a metric will of necessity make use of metric coefficients, g_{ik} and the equation for the distance element $ds^2 = \Sigma g_{ik} dx_i dx_k$ (i, k taking values from 1 to 3) without recourse to the nonconstructible map. Likewise, in the opinion of the writer, problems concerned with chromaticity differences alone are most conveniently solved by using the standard ICI coordinate system and the corresponding metric coefficients.[9] The model exhibited in Fig. 5 may be regarded merely as an interesting curiosity, of little practical utility but a mute reminder that the data on visual sensitivity to chromaticity differences represented in Fig. 3 cannot be represented accurately by unit distance in a plane.

APPENDIX A.

A recent article by D. E. Spencer in this Journal described a non-linear plane transformation asserted to represent the data shown in Fig. 3 with distortions no greater than the experimental errors.[12] The transformed data for only one of the twenty-five ellipses shown in

the simplest possible distributions of values of these coefficients throughout the chromaticity diagram.[9]

3. Parallelograms with sides having lengths $(g_{11})^{1/2}\Delta x$ and $(g_{22})^{1/2}\Delta y$ and cosine of the included angle equal to $g_{12}/(g_{11}g_{22})^{1/2}$ were constructed corresponding to rectangles covering the entire domain of real colors represented in Fig. 3.

4. These parallelograms were assembled in the same sequence as their counterparts in Fig. 3, the smallest modifications of lengths and angles necessary for fitting of adjacent elements being made. Appreciable modifications are necessary because of the large values of Δx and Δy employed in constructing the model.[11]

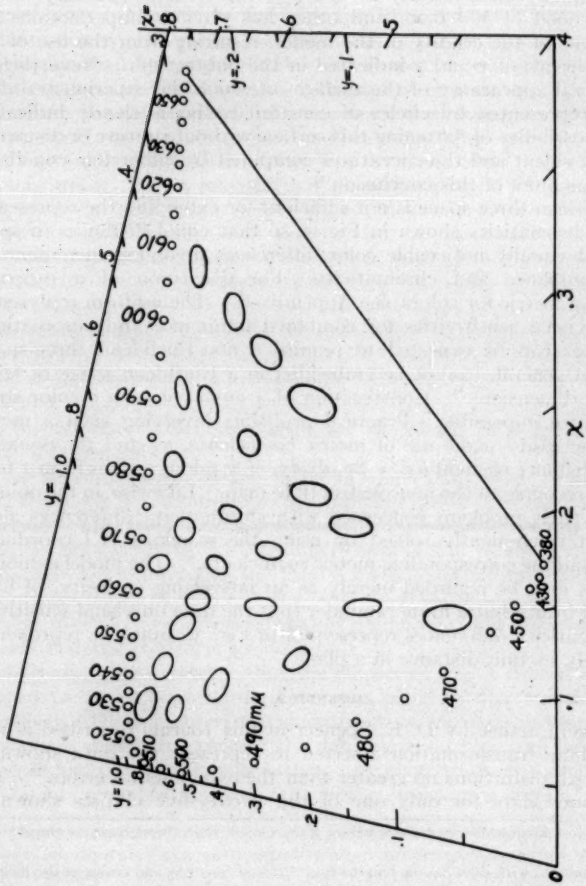

FIG. 4. Standard deviations of chromaticity represented ten times actual scale on Judd's "uniform chromaticity-scale diagram."

Fig. 3 were presented in support of this assertion, and only four such figures were published in an earlier article by P. Moon and Spencer,[13] of which reference 12 was an abridgment. The data for all twenty-five

FIG. 5. Photograph of paper model of uniform chromaticity-scale surface derived from data represented in Fig. 3. Standard ICI coordinates (x, y) are represented by numbered network on surface. Wave lengths along spectrum locus are indicated along the boundary of the surface.

ellipses have been transformed according to the formulas published by Spencer, and the results are shown in Figs. 6 and 7. The eccentricities and distortions of the most reasonable ellipses drawn through these

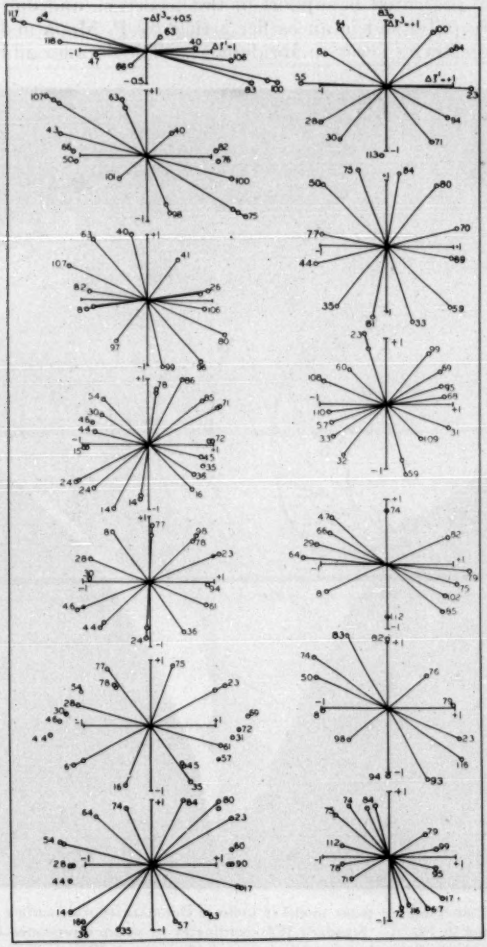

FIG. 6. Distributions of experimental points representing standard deviations of chromaticity matching as they appear in the (ξ^1, ξ^3) diagram of Moon and Spencer. Figures 23 to 29 in reference 6 correspond to the distributions shown in sequence from top to bottom of the left column. Figures 30 to 35 in reference 6 correspond to the distributions shown in sequence from top to bottom of right column. Figure 2 of reference 10 contained errors which have been corrected in this figure.

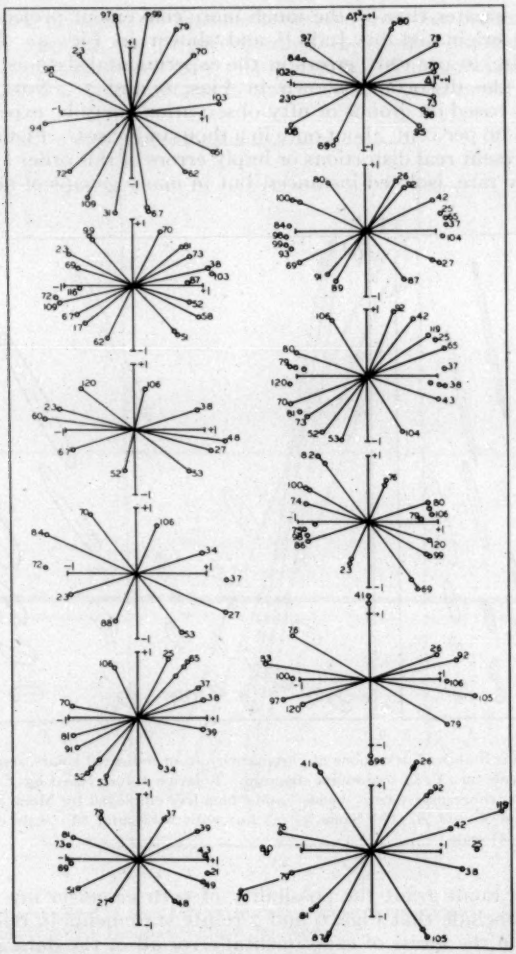

FIG. 7. Distributions of experimental points representing standard deviations of chromaticity matching as they appear in the (ξ^1, ξ^3) diagram of Moon and Spencer. Figures 36 to 41 of reference 6 correspond to the distributions shown in sequence from top to bottom of the left column. Figures 42 to 47 of reference 6 correspond to the distributions shown in sequence from top to bottom of the right column. Figure 3 of reference 10 contained errors which have been corrected in this figure.

points are greater than in the much more convenient projective transformation originated by Judd [14] and shown in Fig. 4. Moon and Spencer cite 30 per cent. errors in the experimental data as reason for accepting the distortions shown in Figs. 6 and 7. Now, standard deviations based on groups of fifty observations may be expected to be in error by 30 per cent. about once in a thousand cases. Figures 6 and 7 either represent real distortions or imply errors of this order and greater not in only rare, isolated instances, but in many groups of neighboring

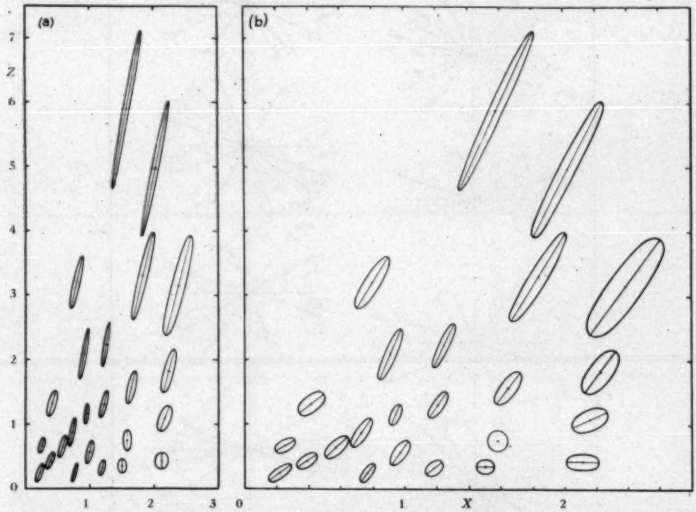

FIG. 8. (a) Standard deviations of chromaticity from indicated colors, represented ten times actual scale on (X, Z) tristimulus diagram. Relative values based on $Y = 1$ used to avoid digression concerning terms "helios" and "blondel" employed by Moon and Spencer. Equal scales of X and Z. (b) Same as (a) but with horizontal (X) scale expanded $2\frac{1}{2}$ times vertical (Z) scale.

points. I cannot grant the possibility of such errors in my data and therefore conclude that Figs. 6 and 7 refute statements in reference 13 that "within the limits of experimental error all of the data are representable by unit circles," "it is doubtful if this appearance (of ellipticity) has any validity," and in reference 12 that "unit distance in any direction and at any point is a measure of the minimum perceptible color difference." Such statements imply that the experimental data contain errors very much greater than there is any reason for suspecting.

The metric proposed by Spencer is derived from her conclusion that "the major axes of the ellipses became essentially parallel" in the projection represented in Fig. 5 of her article. This conclusion is not justified, and Fig. 5 (of reference 12) on which it is based does not

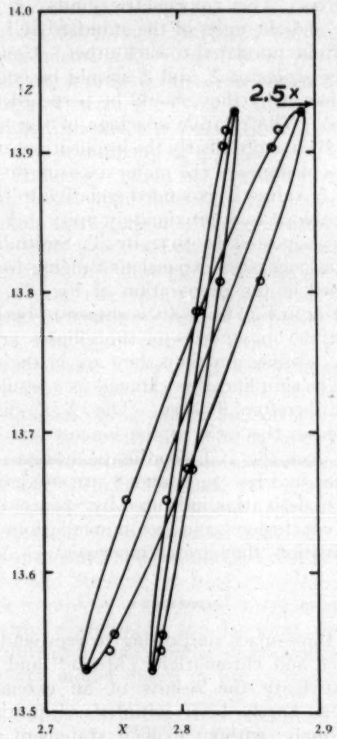

FIG. 8. (c) Standard deviations of chromaticity from $X = 2.81$, $Z = 13.73$. This ellipse is not represented in Figs. 8(a) or (b), nor in Fig. 5 of reference 12. Ellipse resulting from expansion (2.5×) of horizontal scale is also shown.

represent correctly the results of the preliminary transformation specified by Spencer. The appearance of the data when transformed in the manner described by Spencer is shown fairly well in Fig. 8a of this article. The divergences of the axes from parallelism in this figure are

important since slight modifications of the inclinations of ellipses having such extreme eccentricities imply systematic errors in the experimental data much greater than can reasonably be supposed. Divergences from parallelism in Fig. 8a, as in Spencer's Fig. 5, are largely concealed by the use of coordinate scales which exhibit the ellipses with nearly vertical major axes. The colorimetric units of measurement are entirely arbitrary and the units of the standard ICI tristimulus values X, Y, and Z are quite unrelated to each other. Consequently, there is no reason why the scales of X and Z should be equal as assumed by Spencer (nor, in fact, why they should be perpendicular to each other or to the Y-scale). The relative spacings of the scales of X and Z may be chosen to show more clearly the implications of the experimental data. Differences of slopes of the major axes are revealed most clearly when the scale of X values is expanded (relative to that for Z) so as to reduce the average slope to approximately unity. A fivefold expansion of this scale was suggested in 1932 by T. Smith.[15] More recently, E. Q. Adams[16] has suggested expansions ranging from 2.5 to 3. The factor 2.5 was used in the preparation of Fig. 8b. One ellipse, not shown by Spencer or in Fig. 8a or 8b, is shown to both scales in Fig. 8c. It is evident that the major axes of the ellipses are no more nearly parallel in the (X, Z)-diagram than they are in the coordinate system used in Fig. 3. The simplification claimed as a result of the use of the (X, Z)-diagram is, therefore, illusory. The (X, Z)-diagram distorts the ellipses (*i.e.*, increases the ratio of the longest and shortest principal axes) more than does the ICI coordinate system. Since the major axes of the ellipses in Figs. 3, 4, and 8 are not even approximately parallel, the type of derivation indicated by Spencer cannot be applied. Since all of the conclusions and recommendations of Spencer were based on this derivation, they are all incorrect.

APPENDIX B.

In deriving a three-space purporting to represent coexisting differences of luminance and chromaticity, Moon[13] and Spencer[12,13] have attempted to anticipate the results of an extensive experimental program which has barely been initiated. Equations 9 and 10 of Spencer's article imply, without explicit statement or justification of this assumption, that one of the principal axes of every ellipsoid representing equally noticeable color differences is parallel to the Y-axis in ICI tristimulus space (with orthogonal X, Y, and Z axes). Such a result of experiments yet to be performed is by no means evident *a priori*, and being a simplification only in terms of an arbitrary mode of representation this result is hardly to be expected.

Some may be disposed to overlook the discrepancies between experimental findings and the axioms from which Moon and Spencer

derived their color metric, since speculations and analysis unhampered by regard for experimental data sometimes lead to fruitful fields of research. However, if Equations 35 of reference 13 are not entirely *ad hoc*, they should be derivable from the expressions for the metric coefficients, and *vice versa*. If Equations 35 are differentiated, each with respect to all three of the variables, U, Y and V, and if the resulting expressions for $(d\xi^1)$, $(d\xi^2)$ and $(d\xi^3)$ are substituted in the definition of the line element, $(ds^2) = (d\xi^1)^2 + (d\xi^2)^2 + (d\xi^3)^2$, it is found that Equations 34 do not represent the coefficients of dU^2, dY^2 and dV^2. Furthermore, rectangular terms, involving $dUdY$ and $dVdY$, also result from this substitution, although the existence of such terms is denied by Equation 31 and the accompanying discussion. Finally, even aside from the fact that Equations 35 are not derivable from Equations 34 (which, in turn, are based upon fallacious interpretation of available data and questionable anticipation of experimental data yet to be obtained), the three-space described on page 300 of reference 12 is not consistent with the equations that purport to define it. Since ξ^2 (as defined by Equation 35 of reference 13) depends on U and V, as well as on Y, the surfaces of constant Y cannot be planes (as asserted) and therefore cannot be congruent with the plane (ξ^1, ξ^3) diagrams supposedly derived for constant Y (*e.g.*, Fig. 9 of reference 12, or Figs. 6 and 11 of reference 13). Figure 12, with the accompanying text (of reference 13), and the last paragraph of Section 3 of reference 12, are therefore not even consistent with the defining equations, questionable as the latter have been shown to be. Therefore, the three-space described by Moon and Spencer, like their two-space for equiluminous colors, is incorrect because it is the result of incorrect analysis as well as fallacious interpretation of experimental data.

All the material presented in Appendices A and B was outlined in a letter sent to Moon and Spencer on June 17, 1943, shortly after the appearance of their complete article, and three months prior to the publication of Spencer's article in the JOURNAL OF THE FRANKLIN INSTITUTE. The difference of opinion was discussed publicly in October, 1942, and the model shown in Fig. 5 was exhibited on that occasion.[17,18]

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

GAS PERMEABILITY OF COATED FABRICS.

During World War I, the Bureau made a study of methods for determining the rate of passage of gases through balloon fabrics. Out of that investigation, an apparatus was developed that afforded a rapid and precise measurement of permeability. In the intervening quarter of a century this apparatus has been in constant use and it is a tribute to the Bureau's mechanical facilities that little of the original construction has needed to be altered or replaced.

In the present conflict the number and variety of inflatable structures has greatly multiplied. The barrage balloon is an established tool of defense. The performance of the non-rigid airship has convinced the most skeptical of its worth in coastal patrol. Rubber landing boats and pontoons, because of their light weight and compactness, are superior to rigid structures. In the field of sea rescue devices, inflatable vests and the various types of life rafts have become essential equipment in warfare, much of which is amphibious.

In evaluating the coated fabrics entering into these structures, the Bureau's method of determining permeability, applied under the direction of T. P. Sager of the Chemistry Division, has performed a definite function. That the rate of permeation of neoprene was early shown to be nearly one-fourth that of natural rubber determined to a considerable extent its use in balloons. Information obtained in a systematic study of the permeabilities of synthetic rubbers was of assistance when the necessity arose for substitution. The method has served as a standard for those employing other means of measuring permeability. It has been a general practice for manufacturers of fabrics to submit samples for the Bureau's determination, the test specimens employed being returned for redetermination in the manufacturers' apparatus. Occasionally such tested samples have been passed on to other manufacturers to serve repeatedly as reference standards.

The permeabilities of most types of synthetic rubbers are lower than that of natural rubber. The rate of permeation of GR-S or Buna S is, however, very nearly the same. It has long been known that different gases penetrate rubber at different rates. The permeability of rubber to helium is about two-thirds of its permeability to hydrogen. Carbon dioxide penetrates rubber at a rate 2.9 times that of hydrogen. A majority of the synthetic rubbers have approximately these same ratios.

* Communicated by the Director.

Rubbers of the butadiene-acrylic nitrile type differ in having about the same rates for the three gases. In the case of GR-I (Butyl Rubber) and the non-vulcanizable elastomer polyisobutylene (Vistanex) the order is reversed, the permeability to helium being slightly greater than to hydrogen and the rate of passage of carbon dioxide being slightly more than one-third that of hydrogen.

The explanation for this marked difference in behavior would appear to be a difference in the mechanism of permeation in the case of these materials. The higher relative permeability of natural rubber to carbon dioxide results from the greater solubility of this gas in rubber. In the permeation of Butyl Rubber and Vistanex, both of which are characterized by a high degree of saturation and hence relatively inert, solubility of the gas must play a less dominant part in the process, and the mechanism becomes more nearly one of diffusion alone.

LONG-TIME EXPOSURE TESTS OF METALS.

Permanence in service of any structural material is, of course, of paramount importance. This is especially true, however, for aircraft material—metallic as well as non-metallic. The light-metal alloys, unless correctly treated and processed, may be susceptible to corrosion of a very insidious type whereby the metal becomes brittle and weak without showing any very marked change in surface appearance. Laboratory corrosion tests are useful for determining whether or not materials of this general class are susceptible to corrosion of this kind, but for a categorical statement in this respect exposure tests of prolonged duration conducted in environments simulating those of service are necessary. For many years studies of this kind have formed the basis of coöperative projects with governmental aeronautical agencies such as the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

The lack of a suitable permanent installation has long been a handicap in this work. An important requirement is that the site must be closely guarded at all times, and security be assured against encroachment from industry or any other expanding activity. After long negotiations with the Bureau of Aeronautics, such an installation has now been completed on a sea-coastal site at the Hampton Roads Naval Air Station. This installation, which was supervised by a member of the staff of the Metallurgy Division, provides facilities for conducting exposure tests of two kinds—(1) prolonged weathering in a marine atmosphere and (2) repeated wetting by sea-water. The installation, built on piles above water level at the mouth of an inlet, consists of two decks, upper and lower. The latter is close to mean water level, and the supervision of specimens so that they will be immersed twice a day at

high tide involves no unusual difficulty. The height of the upper deck above water level is such that the specimens exposed there to the weathering action of the sea-air are immune to accidental wetting by spray. On this deck will also be placed the racks containing the specimens that are continuously stressed in tension throughout the entire exposure period in the sea-air. In the past undesirable, but unavoidable, interruptions have occurred in these long-time exposure tests as a result of the war time activity and expansion of this naval air station. With the completion of the new installation the chance in favor of freedom from interruption during any test is very good.

COMPARISON OF PLATINUM AND PALLADIUM HYDROGEN-ELECTRODES IN AQUEOUS SOLUTIONS OF ACID POTASSIUM PHTHALATE.

Buffer solutions prepared with acid potassium phthalate are widely used for the calibration of commercial pH meters and equipment. A 0.05-M solution is generally employed and is conveniently prepared from the dry salt and distilled water. The pH value of this solution has usually been determined from the measurements of galvanic cells comprised of various types of hydrogen and calomel electrodes. However, drifting potentials for the galvanic cell have sometimes been reported, thus making impossible the establishment of the exact pH value for the solution. These drifts have been attributed to reduction of the acid potassium phthalate by the hydrogen electrode, to impurities which catalyze this reduction, to the design of the cell, to the unstable states or the unaged condition of the electrodes, to the materials used, to constantly changing potentials of the liquid junction of the solution and the potassium chloride of the calomel half-cell, and to other factors.

Other experimenters using the same kind of cells have reported satisfactory results and potentials that correspond to equilibrium conditions over a considerable period of time, thus making possible the establishment of a pH value. However, this value still included the uncertainties of the unknown potential at the junction formed between the acid potassium phthalate and the potassium chloride of the calomel half-cell.

In the August number of the *Journal of Research* (RP1598), W. J. Hamer and S. F. Acree report new studies of the reproducibility of hydrogen electrodes in solutions of acid potassium phthalate, and of various mixtures of orthophthalic acid and potassium hydroxide at temperatures from 0° to 60° C., inclusive. They employed silver-silver-chloride electrodes that were immersed directly in the phthalate solutions, thus eliminating liquid junctions attendant upon the use of calomel half-cells.

As a result of this recent work, it was found that the potentials of electrodes prepared with platinum sponge increased with time; that the

increase was faster for the thickly plated electrodes than for the thinly plated ones; that the potentials of electrodes prepared with palladium sponge remained at the equilibrium value for a considerable time—in some cases for well over 100 hours; that the characteristics of the palladium electrodes were independent of the thickness of the palladium coating, of the current density used in the electrolysis, of the concentration, composition, acidity, and conductance of the plating solution, and of the composition, concentration, pH, and buffer capacity of the phthalate solutions in which they were used. It was also found that platinum or palladium electrodes having the same type of coating but of different age agreed in potential after 2 hours in solutions of phthalates. The different behavior of palladium and platinum hydrogen-electrodes may be explained by the differences in their catalytic activity.

DETERMINATION OF RESIDUAL WATER IN PURE SUBSTANCES.

Numerous methods have been devised for determining the water present as an impurity in chemical substances. In the *Journal of Research* for August (RP1600) Frank W. Schwab and Edward Wichers describe a new method which has certain advantages of simplicity and sensitivity. It is suitable not only for water, but for volatile impurities in general, in substances which can be melted without decomposition and are themselves not very volatile.

The impurity is separated by fusing the substance in a cell attached to a collecting system and allowing it to freeze slowly while the vapors are collected by pumping them into a trap of known volume, cooled by liquid air. When the trap is warmed to room temperature, the pressure of the vapor within it, if below saturation, together with the temperature and volume, determine the quantity of impurity in terms of moles and, if its identity is known, in terms of weight. An auxiliary procedure permits the impurity to be isolated as a liquid, in a capillary container, and thus to be identified.

It was found that the current standard samples of benzoic acid (39f and 140) contain less than 0.002 per cent. of water and do not adsorb water on exposure to an atmosphere of high humidity. The method is further illustrated by the determination of residual solvents in acetanilide crystallized from benzene and from a mixture of alcohol and water, and of water present in potassium dichromate as entrapped mother liquor.

HYDROLYSIS OF STARCHES BY ANYLASES IN THE PRESENCE AND ABSENCE OF YEASTS.

The enzymic hydrolysis of starches is the basic process for a number of important industrial operations including the preparation of grain alcohol, beer, and certain dextrins for adhesives and sizes. The enzymes

most frequently employed for these purposes are those found in barley malt. Other sources of similar enzymes have long been known, but their general application in place of malt has not been practicable because of the lack of knowledge of their action. In conjunction with the Wheat-Alcohol Committee of the War Production Board, William W. Pigman of the Bureau's polarimetry section has studied the application of various types of enzyme preparations for the conversion of starches into substances fermentable by yeasts. The more important results of the work, as applied to commercial starches, are reported in RP1599 in the August *Journal of Research*. An investigation of the extent of hydrolysis of starches by amylases has revealed that enzyme preparations made from certain molds (*Aspergillus* species), as well as barley malt, are able to break down starches completely to fermentable sugars in the presence of yeasts. Enzyme preparations made from some bacteria (*Bacillus mesentericus*) and from pancreases do not break down starches completely to fermentable sugars, even if the enzymic action takes place in the presence of yeasts. The so-called β-amylases, found particularly in wheat and soy beans, also do not bring about complete saccharification. For certain of these enzyme types, the apparent absence of complete hydrolysis to fermentable sugars seems to be due to the synthesis of unfermentable materials from the products of hydrolysis. The synthesis of such substances by the action of the enzyme preparations on maltose is demonstrated, and the nature of the actions of the various types of enzymes which hydrolyze starch are discussed in relation to the structures of the various starch substances. A procedure for the liquefaction of starch suspensions without the intermediate formation of gels is given.

REVISED COMMERCIAL STANDARD FOR TESTING TEXTILES.

The fourth edition of CS59-44, Textiles—Testing and Reporting, is now available. This is a revision of CS59-41, which is in wide use by textile testing laboratories.

For some years laboratory tests on textiles continued to increase in number, both before purchase by textile commodity manufacturers and retailers and after complaints by users. This increase can be traced largely to women purchasers who, having experienced difficulties with textiles, such as fading, shrinking, stretching, and yarn slippage at the seams, complained of these defects to the retailers.

So important had this matter of testing become by 1934 and so varied were the test methods developed by commercial laboratories that the National Retail Dry Goods Association requested the coöperation of the Bureau in developing a commercial standard to unify methods of testing and of reporting results of tests on woven dress fabrics.

The commercial standard, originally drafted by a committee of testing laboratory representatives and later adjusted and approved by the trade, was first put into effect on April 15, 1936.

Since then, two revisions other than the present one have been issued, the first in 1939 and the second in 1941. The 1939 revision included new methods covering colorfastness to perspiration, wet pressing, and certain refinements to keep the standard abreast of progress. The revision of 1941 was the result of an investigation conducted during the latter part of 1939 by the Technical Committee of the National Association of Finishers of Textile Fabrics, prior to the adoption of new colorfastness specifications for dyed and printed cotton fabrics.

The present revision, undertaken at the request of the Textile Fabrics Association, the National Association of Dyers and Cleaners, and the American Association of Textile Chemists and Colorists, provides nationally recognized methods of testing and reporting results of tests on textiles to determine breaking strength of woven fabrics under atmospheric and wet conditions; bursting strength of knit textiles; colorfastness to chlorine, crocking (rubbing), cleaning (dry and wet), atmospheric gases, laundering, light, perspiration, and pressing (dry and wet); shrinkage in cleaning (dry and wet) and laundering; and resistance to yarn slippage (resistance to pulling out of seams at points of stress). The methods apply to textiles composed of cotton, linen, wool, rayon and other synthetic fibers and mixtures thereof.

Provision is made for five degrees of fastness to light; four of fastness to laundering for cotton, linen, or rayon textiles; and one of fastness to laundering of textiles composed of wool, silk, and synthetic fibers other than rayon, based on an "appreciable change." This term has the same meaning as in the previous edition—that is, a change which, under good light conditions, is immediately noticeable on comparison of the tested sample with the original, or, in the case of staining, when the stain is immediately noticeable on the attached white cloth. If closer inspection or altered lighting is required in any of the above tests to make the change apparent, the change is not considered "appreciable."

The standard also provides for the use of standard dyeings of the American Association of Textile Chemists and Colorists in the calibration of certain testing apparatus.

With the information provided for these tests, it should be fairly easy to determine whether a new fabric is or is not suitable for a given use. The pamphlet includes a brief history of the project, a list of official acceptors, and the membership of the Standing Committee. Copies are available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at 10 cents each.

THE FRANKLIN INSTITUTE.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Table of the Integral of e^{x^2}.—H. M. TERRILL AND LUCILE SWEENY. The values of the integral of e^{x^2} were originally computed by Dawson (*Proceedings of the London Mathematical Society* **29**: 521, 1898) from $x = 0$ to $x = 2$. The table was extended to $x = 4$ in a recent article by Terrill and Sweeny (*Journal of the Franklin Institute* **237**: 495, 1944). In the course of that work, a check was made on some of Dawson's results. Because of the number of last place errors found, it was desirable to recompute the whole of Dawson's table.

x	$\int_0^x e^{x^2}dx$	x	$\int_0^x e^{x^2}dx$	x	$\int_0^x e^{x^2}dx$
.00	.000000	.35	.364833	.70	.833304
.01	.010000	.36	.376176	.71	.849743
.02	.020003	.37	.387601	.72	.866416
.03	.030009	.38	.399111	.73	.883332
.04	.040021	.39	.410709	.74	.900496
.05	.050042	.40	.422398	.75	.917916
.06	.060072	.41	.434180	.76	.935599
.07	.070115	.42	.446060	.77	.953554
.08	.080171	.43	.458039	.78	.971786
.09	.090244	.44	.470123	.79	.990306
.10	.100334	.45	.482313	.80	1.009121
.11	.110445	.46	.494613	.81	1.028239
.12	.120578	.47	.507027	.82	1.047669
.13	.130736	.48	.519558	.83	1.067420
.14	.140920	.49	.532210	.84	1.087502
.15	.151132	.50	.544987	.85	1.107925
.16	.161375	.51	.557892	.86	1.128697
.17	.171651	.52	.570930	.87	1.149830
.18	.181962	.53	.584103	.88	1.171334
.19	.192311	.54	.597417	.89	1.193220
.20	.202699	.55	.610876	.90	1.215499
.21	.213128	.56	.624483	.91	1.238182
.22	.223602	.57	.638244	.92	1.261282
.23	.234121	.58	.652163	.93	1.284811
.24	.244689	.59	.666244	.94	1.308782
.25	.255307	.60	.680492	.95	1.333207
.26	.265979	.61	.694912	.96	1.358101
.27	.276707	.62	.709509	.97	1.383478
.28	.287493	.63	.724289	.98	1.409352
.29	.298339	.64	.739255	.99	1.435738
.30	.309248	.65	.754415	1.00	1.462652
.31	.320223	.66	.769772		
.32	.331267	.67	.785334		
.33	.342381	.68	.801106		
.34	.353569	.69	.817094		

The methods used here for computing are similar to those described in the previous article. The values of the integral were computed directly by series for a set of key arguments differing by 0.1, the intermediate values being then filled in by Gregory's formula.

The extensive "Tables of Probability Functions" prepared by the *Project for the Computation of Mathematical Tables conducted by the Works Projects Administration* (New York, 1941) were used in connection with the infinite series for obtaining the values for the key arguments. The "Tables of the Exponential Function" computed by the same group (New York, 1939) were used for values of the integrand in the calculation by Gregory's formula.

The values of the integrand were tabulated, and differences com-

x	$\int_0^x e^{x^2}dx$	x	$\int_0^x e^{x^2}dx$	x	$\int_0^x e^{x^2}dx$
1.00	1.462652	1.35	2.909389	1.70	6.703576
1.01	1.490109	1.36	2.972107	1.71	6.886609
1.02	1.518127	1.37	3.036554	1.72	7.076010
1.03	1.546722	1.38	3.102792	1.73	7.272040
1.04	1.575912	1.39	3.170883	1.74	7.474971
1.05	1.605716	1.40	3.240894	1.75	7.685089
1.06	1.636152	1.41	3.312893	1.76	7.902692
1.07	1.667241	1.42	3.386951	1.77	8.128090
1.08	1.699002	1.43	3.463143	1.78	8.361611
1.09	1.731456	1.44	3.541545	1.79	8.603595
1.10	1.764626	1.45	3.622238	1.80	8.854399
1.11	1.798534	1.46	3.705306	1.81	9.114397
1.12	1.833202	1.47	3.790835	1.82	9.383979
1.13	1.868656	1.48	3.878916	1.83	9.663555
1.14	1.904921	1.49	3.969643	1.84	9.953554
1.15	1.942022	1.50	4.063114	1.85	10.254423
1.16	1.979986	1.51	4.159432	1.86	10.566632
1.17	2.018841	1.52	4.258704	1.87	10.890675
1.18	2.058616	1.53	4.361039	1.88	11.227067
1.19	2.099341	1.54	4.466555	1.89	11.576349
1.20	2.141047	1.55	4.575370	1.90	11.939086
1.21	2.183766	1.56	4.687613	1.91	12.315872
1.22	2.227531	1.57	4.803412	1.92	12.707331
1.23	2.272378	1.58	4.922905	1.93	13.114114
1.24	2.318341	1.59	5.046235	1.94	13.536906
1.25	2.365458	1.60	5.173549	1.95	13.976426
1.26	2.413769	1.61	5.305004	1.96	14.433425
1.27	2.463312	1.62	5.440760	1.97	14.908695
1.28	2.514129	1.63	5.580987	1.98	15.403064
1.29	2.566265	1.64	5.725861	1.99	15.917404
1.30	2.619764	1.65	5.875565	2.00	16.452628
1.31	2.674671	1.66	6.030293		
1.32	2.731036	1.67	6.190243		
1.33	2.788908	1.68	6.355626		
1.34	2.848341	1.69	6.526661		

puted to the third order, except near the end of the table, where they were taken to the fourth order. The form of Gregory's formula adapted to receding differences was used.

The values for the key arguments were worked out to ten or more significant figures, and the values of the integrand and its differences were carried to seven decimal places. The final results were all rounded off to six places.

BOOK REVIEWS.

ILLUSTRATED TECHNICAL DICTIONARY, edited by Maxim Newmark. 352 pages, illustrations, 16 × 23 cms. New York, The Philosophical Library, 1944. Price $5.00.

Students, scientists, engineers and others whose work covers a broad technical field know the value of a good dictionary, especially from three standpoints. The coverage must be adequate; the arrangement must be so that the sought for information can be found in a minimum of time and with a minimum of effort; the definitions must be clear and complete. Perhaps at no time more than the present has such a book been so useful.

The author of this book has attempted to supply a wide and representative selection of officially approved, standard definitions promulgated by various United States engineering, technical, trade and industrial organizations, as well as by Government agencies. The principle observed with regard to subject coverage is stated to be that the number of terms included for any single subject was determined on the basis of whether that subject is fundamental in all fields and whether it has current importance in the world of technology. Broad coverage is also given to fields of current importance in the war effort and priority is accorded those terms likely to be encountered in the general curricula of technical and vocational schools.

The order of presentation is strictly alphabetical and cross references are used to show relations of word families to each other. In the case of words with like spelling but with different meanings in different fields, the field is indicated in each instance. The number of these is surprising. The definitions are accurate, concise and understandable. There are some ninety illustrations. An appendix contains a list of American standard abbreviations for scientific and engineering terms, units of weight and measure, temperature interconversion tables, table of chemical elements, and geometrical shop data.

This dictionary of 352 pages should be useful to a large number of workers. It is up-to-date and comprehensive.

R. H. OPPERMANN.

GRAPHICAL SOLUTIONS, by Charles O. Mackey. (Second Edition.) 152 pages, drawings and illustrations, 14 × 22 cms. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Limited, 1944. Price $2.50.

The use of curves, diagrams and charts for the solution of engineering problems has several advantages. Aside from a visual conception, there is speed in solution, and when these are coupled with ease and a minimizing of the chance of error this method is recognized as of first importance. The book at hand is a text aimed to give a practical working knowledge of the subject. It is the outgrowth of a course in the School of Mechanical Engineering at Cornell University.

There are six parts on as many subjects, proceeding logically and in an elementary fashion. Mathematics, including algebra, logarithms, some geometry and trigonometry, is all that is necessary. It starts out with a treatment on stationary adjacent scales involving charts for solution of equations for compression ratio $[r = (1 + c/c)]$, and logarithmic scales. A very important topic to the engineer is that of sliding scales, next taken up. It is shown how to design slide rules to solve different types of equations. Graphical representation of equations containing these or more variables is discussed under network or intersection charts. This is followed by alignment charts, the use of which is becoming more widespread in various fields of engineering. The last two chapters are devoted to empirical equations first referring to non-periodic curves, then periodic curves, which are composed of the repetition of values of one variable at regular, repeated intervals of a second variable. This latter is new in this second edition of the book.

The presentation is clear with many illustrative examples and exercises. It is a good text for the student or practicing engineer.

R. H. OPPERMANN.

COMMUNICATION CIRCUITS, by Lawrence A. Ware and Henry R. Reed. (Second Edition.) 330 pages, illustrations, 14 × 22 cms. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd., 1944. Price $3.50.

Perhaps the most interesting field for study in electrical engineering is the transmission line for power and its extension to the transmission line for communication. The two have essentially different purposes but it is convenient to look upon one as the outgrowth of the other. And so it is actually in a logical course of study. Communication engineering has made and no doubt will make considerable progress. The importance attached to the use of microwaves in our present national emergency and the vital part which they are destined to assume in our normal lives is significant. It is therefore of special importance to present in a clear and logical manner a course of study in this interesting and promising field.

This textbook assumes a knowledge of calculus and the elements of alternating current theory in its coverage of the basic principles of communication lines and their associated networks including the frequency range from voice frequencies through the ultra-high frequencies. It opens with a brief review of some of the facts connected with resistance, conductance, inductance and capacitance of a line and it gives here an elementary treatment of the coaxial line. This leads to a discussion on certain transformations of the elementary T and π sections, and there follow a number of network theorems, the ideas of characteristic impedance, propagation constant and distortion, and the consideration of certain simple transmission lines. The problems involving attenuation, terminating impedance, and reflection are raised and discussed under the heading of the infinite line and the general line and later there are taken up the concepts of "reflection factor" and "insertion loss" with the presentation of miscellaneous material concerning measurements on lines.

In order to develop the theory of filters a beginning is made with a consideration of some fundamental properties of reactive networks which proceeds to design equations for filters meeting the requirements of a pass band over an interval of two specified frequencies, while outside of this band there exist a region of attenuation and a characteristic impedance at a certain frequency. Later the disadvantages of such filters are taken up and methods are developed to overcome them. Here resort is made to some mathematical experimentation which when followed leads to desired results. An illustrative design of a composite filter is presented, then the general problem of impedance matching is treated in an elementary manner and some applications of matching to high frequency transmission are considered.

The general problem of ultra-high-frequency transmission in wave guides is given good coverage before taking up the mathematical theory of the rectangular wave guide and the derivation of its fundamental equations. A treatment of the cylindrical wave guide forms the basis for application to the coaxial line of which only the elements of the electromagnetic theory are presented. The last chapter in the book outlines briefly a number of experiments which are designed to lend considerable aid to the better understanding of various portions of the text material. Appendixes include an introduction to Fourier series, loop equations, hyperbolic functions, Maxwell's equations and other useful information. There is a subject index in the back of the book.

The authors make free use of worked out examples in the text to impress and show the practicability of the material. And there are numerous problems for exercise. The text is well constructed and well presented.

R. H. OPPERMANN.

PHYSICS: A Textbook for Colleges, by Oscar M. Stewart. (Fourth Edition.) 785 pages, illustrations, 15 × 23 cms. Boston, Ginn and Company, 1944. Price $4.00.

This is the fourth edition of this book since 1924, other editions having been reviewed here. The book is so well known that it is unnecessary to give more than a brief reference

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to its scope. The topics of elementary college physics are covered here in the familiar order of mechanics and properties of matter, heat, wave motion and sound, magnetism and electricity, and light. Under these topics many changes have occurred, some incorporating new fields, others providing new conceptions of previously basic thoughts. Not only with regard to the textual matter do changes apply but in ways of presentation and arrangement they are of particular import, reflecting experience.

An attempt has been made in this edition to improve the pedagogical value of the book without changing the purposes. In so doing, parts have been rewritten and other measures taken to gain this end. Among them are the following: The chapter on Vibratory Motion under the first topic has been rearranged to bring out the reason why some knowledge of simple harmonic motion is useful. An illustration of the principles of physics involved is emphasized in the chapter on Some Applications to Meteorology. Additions have been made to the subject of electronics and to the chapters Atomic Transformations and High Frequency Oscillations and Electrical Waves. The properties of electrical waves have been more closely connected with those of light waves. The treatment is harmonious with the spirit and results of the new physics.

An appendix contains much useful general information including a section devoted to Notes on the Scientific Method. The author in this, as in previous editions, lays much value on the scientific method of reasoning and expands sections, fills in gaps and consolidates references in the body of the text. There are a great many problems for exercise throughout; the answers to them are given. The size and style of type in the text are also noteworthy. It makes for ease in reading. A subject index at the end adds value in the way of reference. The book is up-to-date and is a good exposition of elementary physics.

R. H. OPPERMANN.

TODAY'S GEOMETRY, by David Reichgott and Lee R. Spiller. (Revised Edition.) 400 pages, photographs, drawings and illustrations, 16 × 24 cms. New York, Prentice-Hall, Inc., 1944. Price $1.96.

It is becoming realized to a greater and greater extent that in order to make a subject interesting it is not necessary to "sugar coat" it or to eliminate the most difficult parts. The trend meeting with the most success involves making the subject real, tangible, or applying it to practical everyday things in life. Geometry, for instance, need not be an isolated mathematical topic, but since it enters into our lives so directly it is a means to a greater understanding.

Perhaps those best situated to see the need for the new approach in geometry are the high school teachers. The authors of the book at hand are connected with the New Haven High School, New Haven, Conn., and the title of the book indicates the method of presentation. The book is in its second edition, planned to meet today's needs as well as those of the days ahead. It fits in its place in the procession of mathematical studies just after algebra. The introduction incorporates the modern method where many diverse citations are given and well illustrated. The following chapters deal with triangles, parallel lines and quadrilaterals, location of points and objects, polygons, the circle, solids, and solving right triangles by trigonometry. There are many illustrations and drawings applying to practical affairs and structures interwoven in the text. Included in the new material is that on global maps and a new chapter on vectors and air navigation.

An important part of the book appears in the back. It is entitled "Refresher in Arithmetic and Algebra." It is cleverly gotten together and should be helpful in integrating the work of earlier grades with geometry. Appendixes contain much helpful information in formulas and tables, and especially the summary of theorems and constructions. The text throughout reflects a keen insight into the situation of the student, and every means is taken to make the subject interesting and impressive.

R. H. OPPERMANN.

BASIC MATHEMATICS FOR WAR AND INDUSTRY, by Paul H. Daus, John M. Gleason and William M. Whyburn. 277 pages, tables and illustrations, 15 × 22 cms. New York, The Macmillan Company, 1944. Price $2.00.

The war, probably more than anything else, has brought the realization to many of the value of training in basic mathematics. Such training is a necessity in many activities of warfare, in wartime industry, as well as in peace time. The only difference between peace and war in this respect is that the mathematics involved in destruction is much more spectacular and rapid than the mathematics of construction. The necessity is there in both cases. But now, when there is a demand for those with knowledge including mathematics, many schools have sprung up creating a demand for suitable texts. The book at hand is designed for this purpose.

It is composed of 246 pages of text. Careful selection has been made of elementary mathematics and they are presented in a carefully organized manner. Presupposition is made of a familiarity with the elementary operations of addition, subtraction, multiplication and division in whole numbers. Consequently the work starts with common fractions and proceeds through mensuration for the arithmetical coverage. In algebra, the next topic, the start is made from the very beginning and ends with quadratic equations. The largest sections are devoted to geometry and trigonometry, and finally spherical trigonometry which includes some elements of navigation. In the back are tables of logarithms and trigonometric functions.

The work is thoroughly practical in choice of both topics and treatment. Mathematical rigor in the way of exercises is not diminished. The exercises are applicable to activities of the day and the answers are given in the back. This widens the usefulness of the book for home study and as a refresher.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

The Physics of Music, by Alexander Wood. 255 pages, photographs and illustrations, 15 × 22 cms. Cleveland, The Sherwood Press, 1944. Price $8.00.

Peace, Plenty and Petroleum, by Benjamin T. Brooks. 197 pages, tables and illustrations, 14 × 20 cms. Lancaster, The Jaques Cattell Press, 1944. Price $2.50.

Organic Chemistry, by Louis F. Fieser and Mary Fieser. 1091 pages, tables and illustrations, 16 × 24 cms. Boston, D. C. Heath and Company, 1944. Price $8.00.

Colloid Chemistry, Edited and Collected by Jerome Alexander. 1256 pages, photographs and illustrations, 16 × 24 cms. Reinhold Publishing Corporation, 1944. Price $20.00.

CURRENT TOPICS.

Digestion Clears the View.—Good digestion makes for clearer vision in the microscope, plant scientists of the U. S. Department of Agriculture have discovered. The digestion, in this case, is of the object to be examined under high magnification.

Searching for fundamental facts of heredity, scientists need to know more about the interior of cells, and particularly about the appearance and arrangement of the chromosomes that are believed to control the hereditary behavior of the plant. Minute as single cells are, the scientists have devised ways of making microscope slides that expose cells in single layers and so enable the observer to study single cells. But the cell walls are not clearly transparent and interfere with views of the cell interiors.

S. L. Emsweller and Neil Stuart of the Agricultural Research Administration, trying to reduce this interference, applied solvents and caustic chemicals to dissolve or eat away part of the cell walls. Failing with these, they turned to organic preparations and have had better success. An enzyme preparation literally digests away part of the cell wall and in some way affects the internal structure, causing chromosomes to spread out readily. The microscope slides of "digested" cells give clearer views of the chromosomes.

They have also had promising results with substances prepared from fungi that have been studied in wartime research on decay and destruction of fabrics such as tents, uniforms and sandbags. Carefully controlled, the substances that break down the fibers of a sandbag can also be used to break down part—and only part—of the wall of a plant cell.

Early experiments have been mainly with pollen cells. Results with cells from roots have been less satisfactory. Other enzymes and digestive substances will be tested with root cells in developing the new and promising tool for plant research.

R. H. O.

CURRENT TOPICS.

ARMY AND NAVY NOTES.

Electronic System Speeds Process in Penicillin Production.—Impelled by recurring demands from American fighting fronts and home front sick rooms for increased production of the renowned drug penicillin, the Radio Corporation of America has developed an electronic system that in 30 minutes completes an operation which requires 24 hours by the conventional system in the bulk reduction of purified penicillin solution—a time-consuming step in production.

This achievement was announced jointly by the R.C.A. Laboratories, Princeton, N. J., and E. R. Squibb & Sons.

Tests at the new Squibb penicillin production plant at New Brunswick, N. J., showed that in one day's operation a single R.C.A. electronic apparatus had a potential capacity of concentrating penicillin solutions containing approximately 2,000,000,000 Oxford units. The speed of operation is about 48 times as fast as it is in one of the conventional "freeze-drying" machines. The number of units concentrated in 24 hours in an R.C.A. electronic apparatus corresponds to approximately 20,000 ampuls, each containing 100,000 units—an amount sufficient to treat 4,000 patients requiring 500,000 units each.

Individual credit for the development of the high-frequency dehydrator has been given to Dr. George H. Brown, 35-year-old research engineer, of R.C.A. Laboratories, who was inspired in making his invention by a newspaper story he read on the production problems of penicillin, the demand for which, overseas and at home, has far exceeded the supply. He received helpful assistance from his associates, R. A. Bierwirth and Cyril N. Hoyler, and from scientists at the Squibb Biological Laboratories, the latter providing most of the penicillin solution for his experimental runs.

Dr. Brown's radio-frequency system deals directly with the problem of the bulk-reduction of purified penicillin, rather than with the production of penicillin itself.

After the penicillin is produced by the mold either by surface or submerged fermentation in containers holding up to several thousand gallons, the penicillin-containing broth is separated from the mold by filtration and the crude penicillin extracted from the broth with an organic solvent. It is then given an elaborate series of chemical treatments which finally remove most of the impurities and reduce the bulk by about 600 times. Much painstaking research in the Squibb Laboratories has contributed to the perfection of these processes and to the designing of equipment to carry them out on a large scale.

This is the point where the final bulk-reduction must begin for, while the penicillin in solution now has a potency of about 40,000 units per cubic centimeter, the objective is to attain 100,000 units per cc. Once that is accomplished, the penicillin is freeze-dried to powder form in ampuls or vials for shipment to places of urgency designated by the War Production Board.

Since ordinary heat methods of evaporation destroy the effectiveness of penicillin, the bulk-reduction in plants under WPB control has been achieved

through freeze-drying, a process in which the penicillin solution is caused to evaporate in a high vacuum at below-freezing temperatures.

Dr. Brown's electronic bulk-reducer employs radio-frequency current to concentrate the penicillin solution. His system consists of three large glass bulbs, connected in vertical series, and attached to a pump that maintains a relatively low vacuum. In this vacuum, the solution boils at 50 degrees Fahrenheit, a temperature that does no harm to the drug during the brief period of its exposure.

To the setup is connected a 2,000-watt radio-frequency generator. Electrodes carrying the output of the electronic generator are attached to the base of the lowest glass bulb which, when the unit is in operation, holds about 200 cubic centimeters of liquid. From the base of the bulb, a glass tube extends downward for several inches, so that when a beaker of penicillin broth is placed on a platform beneath, it almost reaches the bottom of the beaker.

As the vacuum pump starts, the suction draws the solution into the base of the lower bulb. The radio current is turned on and, as the current passes through the solution, heat up to 50 degrees is created and the liquid boils. This causes an evaporation at the rate of two litres an hour.

Dr. Brown recalled some of the problems with which he contended as he sought to perfect his invention. One of the difficulties that had to be overcome in the original setup of two connected glass cylinders was excessive foaming, which slowed up the process. The thought occurred to him that glass marbles placed in the connecting necks of the cylinders might be effective.

The scientist sent out a messenger, who visited all of the shops in the town of Princeton without so much as finding a marble. Dr. Brown called his home and enlisted his wife to search his children's belongings. Still no marbles. Finally, his wife reported that one of the neighbor's children, who "played for keeps," had a shoe-box containing 1,000 glassies. This supply was tapped and science moved ahead.

Dr. Brown's final solution, however, was to replace the two glass cylinders and marbles with the three glass bulbs of his model, adding a water coil. Further, the penicillin was "degassed" before placing it in the containers. Dr. Brown explained that boiling occurs in the bottom bulb, the next bulb takes care of excessive foaming, and the third is "just for good measure."

In succeeding with his electronic bulk-reducer, Dr. Brown has added an important chapter to the history of radiothermics, the application of radio heat, which is speeding and improving many vital processes in war industry. Achievements of radiothermics now run the gamut from gluing, annealing, sewing and dehydrating to drying, case hardening, riveting, detonating, welding and soldering. In fact, more electronic power in kilowatts is being used in the United States for industrial purposes than by all radio transmitters in broadcasting and communications.

R. H. O.

Trucks Put " On Ice " in Army Refrigerator.—(*Refrigerating Engineering*, Vol. 48, No. 1.) A refrigerator large enough to put an entire fuel servicing truck "on ice" is now being used by Equipment Laboratory of the Engineering Division research engineers at Wright Field, Ohio, to test the ability of Air Forces equipment to take the punishment of arctic weather.

The refrigeration equipment was built by the York Corporation after having been designed by its engineers, in collaboration with Material Command Aircraft Laboratory engineers. The 80 ft. long cold chamber is capable of operating at temperatures lower than — 70 deg. F. In it, the army gives a "pre-induction" to all types and descriptions of Army Air Forces equipment. One of the chief uses for the low temperature tests is to determine the starting and running efficiency of internal combustion equipment, such as ground and aircraft heaters and accessory power plants, in sub-zero climates.

The Material Command's refrigerator, 25 ft. high and 25 ft. wide, is divided into two compartments so that separate tests can be carried on simultaneously at different temperatures. Its 16 in. thick double doors weigh four and a half tons and are large enough to admit nearly any piece of Army Air Forces apparatus. Cooling equipment for the cold room is located in the ceiling, where 60,000 cubic feet of chilled air is circulated each minute during the pull down period.

At — 70 deg. F., workmen in the room must wear helmets to prevent sudden freezing of the nasal and throat passages as well as lung tissues.

R. H. O.

Rubber Sheeting Speeds Up Martin Stretching Operations.—HARRY F. VOLLMER. (*Machinery*, Vol. 50, No. 11.) Thin rubber sheeting is now being used in the factories of the Glenn L. Martin Co. as a substitute for the grease that is generally applied to the form or stretch-block in stretching operations on aircraft skins.

Grease is ordinarily applied to the stretch-block in generous quantities, so that the sheets of duralumin can slide readily on the blocks as they are being stretched. The application of the grease not only takes considerable time, but also entails a number of other operations in addition to those required in the actual working and machining of the skins. For example it is necessary to scrape off the grease from the stretched work immediately after stretching. In the Martin plant, before the adoption of rubber sheeting, this was done by a group of employees equipped with rubber scrapers and wiping cloths.

The substitution of rubber sheeting $\frac{1}{32}$ inch thick for the grease in stretching operations brought about revolutionary changes in production procedure eliminating all the disadvantages of grease and the incidental operations required for grease removal. The sheeting is laid loosely but evenly over the stretch-block, after a light coating of machine oil has been wiped on the stretch-block. Then a production run of skins can be stretched without lifting the sheeting from the block. By using the rubber, a working surface is obtained on the stretch-block that slides with the work.

Pits or other small defects on the stretch-block have no effect on the quality of the work because the rubber covers and compensates for such defects. It is not necessary either to polish the stretch-blocks to the high degree of smoothness that was essential to satisfactory stretching when grease was used as a lubricant.

The greatest advantage of rubber sheeting is the saving in time derived from its use. Two sheets of duralumin can be stretched at one time on top of each other. This fact, together with the elimination of greasing, has tripled the production in skin stretching operations.

R. H. O.

Induction Hardening Advantageous in Fabrication of Gun Parts.—(*American Machinist*, Vol. 88, No. 15.) Hundreds of jobs involving selective hardening, brazing and soldering on parts and assemblies for Boys, Bren, Browning, Colt and other guns are now being done at the John Inglis Company Ltd., Toronto, by the induction heating method. Induction hardening of these parts eliminates flame and lead-pot hardening, is faster, and avoids the problem of removing lead from recesses. Soldering and brazing by the process have speeded assembly operations. Some jobs are handled on a batch basis, others run continuously. In all cases, spark-gap induction heating equipment provides satisfactory heating cycles, permits ready attachment of leads for the induction coils, and broad tables provide room for fixtures of various size. Many of the fixtures are largely of wood.

One of the jobs being handled on a batch basis is that of hardening three closely related machine surfaces in the interior of the Bren gun body. Induction hardening provides a means of improving the quality of the component, avoids distortion of an item that has passed through many expensive machining operations and gives a simple means of applying heat within a confined space.

The Bren body is placed vertically in a wooden fixture that is fitted with a formed induction coil made to enter the recess. A locating pin and a latch hold the part safely in position. By pushbutton the operator starts the timed heating cycle, which has a duration of 37 sec. after which the current shuts off automatically. Thereupon the operator removes the piece from the fixture and suspends it in a quench tank. As gun bodies are removed from the oil, they are placed upon a removable drain pack placed on top of the quench tank.

Assembly of the Bren flash eliminator tube and bracket is done by silver soldering. Joint surfaces of components are coated with silver-solder paste, and the bracket with a ring of silver-solder wire is slid over the tube, being positioned with a gage. Thereupon the assembly is placed in a four position fixture, consisting of four short tubular members spaced vertically on a bar attached to the ram of an air cylinder. When the operator steps on the treadle, the cylinder raises the fixture to the heating position, current is thrown on, and the automatic induction heating cycle of 42 secs. transpires. In other words, four pieces are assembled at once in this cycle, and the manual work involved is comparatively light.

R. H. O.

High Frequency Electric Field Used in Processing Foodstuffs.—(*Electrical Engineering*, Vol. 63, No. 7.) Uhlmann patent 1,992,515 entitled "Apparatus for the Preparation of Foodstuffs" available for licensing through the Alien Property Custodian, describes equipment by which raw food materials are subjected to a high frequency electric field for processing. The apparatus is a wave oven which consists of a transformer coil supplied with 220 volts at 50 cycles, a secondary coil connected to a capacitor, a spark gap, and another coil that emits a high frequency field of 800 meters or less.

The method may be used to can foodstuffs as well as to cook and preserve them. Advantages claimed are saving of time, improvement in taste, and retention of vitamins and mineral salts. Fruits can be cooked in their skins without loss of shape, and milk is freed of living organisms without heating to 100 degrees Centigrade, or boiling temperature. It may also be used to

brew coffee and tea, obtaining the same extraction at a maximum temperature of 70–75 degrees Centigrade (169 degrees Fahrenheit) as compared with the temperature of 100 degrees Centigrade when made by the usual method.

R. H. O.

Performance of New Walkie-Talkie in Anzio Action Praised.—(*Electrical Engineering*, Vol. 63, No. 7.) In its baptism of fire in the Anzio beachhead assault the latest Signal Corps "walkie-talkie," or SCR 300 radio set, met and exceeded every expectation for range and reliability and was lauded as the most valuable item of radio equipment in the attacking division by the division signal officer.

The SCR 300 set, omnipresent at the Anzio landing, was used in all radio nets from division to infantry companies as well as in Cub observation planes and afterwards was termed the most successful instrument yet devised for amphibious communications. Its range is triple that of the former "walkie-talkie," and it has remarkable clarity of tone attained through frequency modulation, which eliminates static. Netting of the sets on one frequency is facilitated by the substitution of the superheterodyne for the superregenerative receiver. An extra goose-neck type antenna supplements the standard vertical antenna of such sets. This permits transmission even when the operator is prone on the ground. A headset for the operator and a handset for the officer in command accompany the new model. Miniature radio tubes prolong the life of its batteries and add to its compactness. The set is treated to withstand rain and immersion in water for short periods. Although the new model weighs 35 pounds, as did the older one, its portability is enhanced by an extra strap which encircles the soldier's waist and distributes the set's weight more evenly.

R. H. OPPERMANN.

Robot Bombs.—A statement under the section "Spotting the Air News" in *American Machinist*, Vol. 88, No. 15, points out that Germany's flying bombs have important implications for the future. They are not new because thousands of air minded tinkerers have had the idea and Mr. Kettering of General Motors filed a patent claim on one long ago.

The bombs are demonstrating the feasibility of jet propulsion for unmanned flying weapons. They can be accurately aimed at long range by (a) pilots who would bail out close to the target, (b) by electronic control, already in use, from a "mother" plane following a formation of bombs, or (c) they could be made automatically to follow radio beams such as are now in use on scheduled air lines.

The winged bomb is navigated by a robot (gyroscopic) pilot or "iron mike" like those used on steamships and air liners to hold course with intermittent correction. There is in this system an element of cumulative error which, if the robot is left uncorrected, cuts down its accuracy as the range increases.

It is incorrect to call the flying bombs "rocket bombs." These bombs are jet propelled. A jet engine burns a large volume of air with its fuel oil,

just as internal combustion engines do, and its thrust is largely reaction from the impact of hot air and gas from the jet against the body of air.

Rocket power is different. The rocket's mixture of oxygen and chemicals which it burns is sealed up in the rocket's magazine. It needs no air to burn. Part of its thrust is pure reaction from the continuing explosion—equal and opposite reaction known to all students of physics. Therefore it could fly in a vacuum, or beyond the atmosphere. But when the fuel in its magazine is burned out, it's done. The jet engine, on the other hand, can function as long as it receives fuel from the tank, to mix with air. Rockets, so far, are useful only for a few moments as airplane take-off boosters. When burned out, they are dropped, and may be reloaded.

R. H. O.

Research and Plastics.—Dr. J. A. Hutcheson, associate director of Westinghouse Research Laboratories, recently referred to plastics for industry in terms of the scientist's and the engineer's point of view. In this field, plastics are rightfully considered prime materials and not ersatz materials. Industrial research and development is not aimed at providing substitutes, but at providing new prime materials which can do better jobs than anything in existence.

Westinghouse produces a large portion of the laminated plastic materials manufactured in this country because it needs an electrical insulating material with good structural properties for manufacturing electrical products. Micarta, a laminated plastic material which is made from fabric or paper impregnated with synthetic resins and compressed under heat into a solid substance, fills this need. Micarta is an excellent insulator; a piece one-sixteenth of an inch thick will withstand 45,000 volts of electricity. It is also very tough; pound for pound it exceeds the strength of structural steel.

Therefore, back in 1909 Westinghouse started producing this particular kind of plastic. During the last five years, millions of pounds of Micarta were produced and output has increased many times since the beginning of the war. Its uses have been both varied and unique. If you are accustomed to thinking of plastics in terms of a decorative but fragile material, you may be surprised to learn that steel mill bearings made of Micarta can carry a million-pound load on a modern rolling mill. When the war came, Micarta proved ideal for military service—it is now being used in helmet liners, in bomb racks, and in aircraft control pulleys. In addition, this plastic is being used for propeller shaft bearings on Navy vessels, in switchboard and radio panels, and in a variety of applications in paper and textile mills. Micarta is an old industrial plastic. But research and development have continued at the laboratories, and one of today's newest plastics belongs to this family.

Westinghouse research engineers have contributed many advances in plastics, including four recent timely developments. Two of these new plastics find application in the field of electrical insulation. One of these, called Fosterite, is even now tremendously important in radar units; the other is a synthetic shellac possessing steel-like strength. The two other developments are significant in the forming of plastics; one is similar to the technique of pressing metals, the other to the casting of metals. The first, called hot forming, is a technique of forming intricate structural parts from flat sheets of laminated plastics. The second, called preforming, is a process of "casting"

a fluid mass of resin-impregnated fibres. Three research engineers, Doctors Hill, Perry, and Bates, who have been solving problems in plastics for many years and directing their use, are largely concerned with these four new developments at Westinghouse.

A decade from now, Fosterite may be recognized as the greatest advance in electrical insulation for many years. Four years of intensive research by Dr. Hill and his associates created Fosterite along with the steel-like resin. Generally, productive research is a lengthy, painstaking process. For example, research on Micarta has been going on for thirty-five years with steady improvement of the material and extensions of its applications. However, every once in a while, key developments noticeably accelerate progress. The technique of hot forming and the new plastic Micarta 444, especially formulated for this type of molding by Dr. E. R. Perry, are new, war-born developments.

Micarta 444 is so scientifically matched to the process of hot forming that the material retains its unusual properties even after being formed. The process itself produces intricately shaped parts from ordinary sheets of such plastics. This technique is analogous to the pressing of steel. Another technique, analogous to the casting of steel, extends the formability of plastics even further. This process is called preforming, and Dr. A. Allan Bates forsees a tremendous future for this process of forming high-strength parts of intricate shapes.

Fosterite, high-strength resin, hot forming and preforming are typical of recent research developments, some already pressed into use by the war, all of great promise in post-war applications. Designers and engineers will use these materials not as substitutes, but as new materials to make better things for home and industry. These and similar developments are evidence of the better things ahead.

R. H. O.

100,000 Turbosuperchargers Recover 66 Times Power Generated by Boulder Dam.—With the shipment of the 100,000th turbosupercharger produced in General Electric plants, the company has given Uncle Sam's fighting planes the means of recovering at high altitude more than 66 times the power generated at Boulder Dam, or almost twice the output of the entire nation's steam power plants combined.

Aircraft engines, like crews, require oxygen at high altitudes, and a turbosupercharger recovers for a 1200-horsepower engine the 920 horsepower it would otherwise lose at 34,000 feet altitude. Thus 10,000 turbosuperchargers recover 92 million horsepower in enabling American planes to function at maximum strength at high altitudes.

Engineering and production records that have been achieved since our entry in the war include the following:

Power Recovery. Without a supercharger, a 1000-horsepower aircraft engine as built in 1941 would develop only 370 horsepower at 25,000 feet. But in 1944 engines rated at 1200 horsepower and to be flown at 34,000 feet would deliver only 280 horsepower by themselves, so turbos to recover the lost 920 horsepower were developed for mass production. This was a new high in recovery.

Weight. Although called upon to recover more horsepower, Pearl Harbor turbos and those of today weigh substantially the same—135 pounds. Thus aircraft designers are spared their chronic headache—extra poundage.

Power-recovery Ratio. The basic test for rating efficiency of energy is the amount of horsepower delivered per pound weight of the generating device. For the 1941 turbo, the weight per turbo-recovered horsepower was .214 pound; for today's model, .146, or a weight decrease (and therefore an efficiency increase) of one-third.

Cost. The Pearl Harbor model supercharger cost the government three times as much as today's improved unit. In terms of cost per recovered horsepower, today's turbo costs less than one-fifth as much as the 1941 model.

Servicing. In 1941 a turbosupercharger required a major overhaul at the end of 300 hours; today's model requires only a minor overhaul after 1300 hours, or more than four times the operating period. This improved endurance compares with engine overhaul requirements of 300 hours three years ago and 500 hours today.

These records were made possible by a variety of engineering and production contributions of the Army Air Forces, G. E., Ford, Allis Chalmers and other manufacturers and by team-work in co-ordinating design and manufacturing programs. Improvements include:

New Alloys. One part of a turbosupercharger must stand red-hot heat from the engine's exhaust gases while another is withstanding the sub-zero of the slip-stream at high altitudes. The 1944 turbo must operate at increasingly cold altitudes, yet spin at greater, and therefore heat-increasing, speeds. Metallurgists supplied the necessary new materials, notably a new alloy especially suitable for welding.

New Ball Bearings and Lubrication. Ball bearing manufacturers developed bearings capable of withstanding the higher speeds, and an oil jet for lubricating them more efficiently than the previous splash system.

New Metal. To cope with the recent aluminum shortage without materially increasing the weight, the compressor casing was changed from cast aluminum to pressed steel.

New Process. Previously small "buckets" or blades, of spinning wheels in the turbo, were forged and machined. Now metal is poured into moulds, similar to those used in casting dental plates, and compressed under heat with a mass-production precision which eliminates machining.

Welding. By flash-welding wheels to shafts and simplifying design of other parts to facilitate production-line welding, considerable time has been saved.

Manufacturing Methods. Long, tedious hand methods were circumvented by revamping milling technique so that many operations now require minutes rather than hours. Balancing, assembling and testing have undergone widespread changes in simplification of operations, permitting less skilled workers new to industry to participate on a large scale.

Perhaps the most spectacular battle application of turbosuperchargers is on the B-29. The basic function of this plane's eight turbos is to feed enough oxygen into the four 2200-horsepower engines to take it to undisclosed heights above enemy flak. The turbos on two of the engines also pressurize the cabin, enabling members of the crew to operate without oxygen masks, which they

use only during bombing runs or in emergencies. The peace-time Boeing Stratoliner used separate cabin superchargers for this same purpose, but the B-29 is the first plane to use the engines' turbos for pressurization.

R. H. O.

Jet Propulsion Plant.—General Electric's second largest wartime plant, built two years ago for the manufacture of war equipment which is no longer required by the allied forces, is being converted for the production of jet propulsion aircraft turbines.

The jet propulsion airplane turbine, first conceived by Flight Commander Frank Whittle and built by the British Thomson-Houston Company, Ltd., an associate of General Electric, was sent to this country for further development by General Electric's engineers. Mr. Whittle came from England soon after, and spent three months here, but kept his identity so well concealed that few knew of his presence, even though associated with him in the G-E laboratory. A number of units have since been built, and the first of these new type planes to fly in this country was equipped with a jet power plant manufactured by General Electric.

The basic principle which underlies jet propulsion is not new. It has been known for hundreds of years, since the days of Galileo and Isaac Newton. The new power plant is a successful and ingenious application of one of Newton's laws of motion—the law which says that to every action there is an equal and opposite reaction.

This principle is familiar to everyone. It is the backward "kick" of the gases produced in a skyrocket that drives the rocket upward and forward. And there is a still more familiar example, the rotary lawn sprinkler. The jets of water go in one direction, and the reaction causes the frame that holds the nozzles to revolve in the opposite direction. You might say that the lawn sprinkler was whirled by jet propulsion.

"An aspect of jet propulsion that puzzles many people is that in the substratosphere, where the air is very thin, an airplane propeller has a hard time. It has less and less air to bite into and pull the plane along," according to Harry A. Winne, engineering vice president of General Electric. "Actually up there, the propellerless jet turbine works better, because the air resistance on the plane is less, and the jet power plant doesn't have to have air to push against. It doesn't push against anything that it doesn't provide itself. The jet of gases moves in one direction; the inevitable reaction pushes the plane in the opposite direction. Theoretically, the jet propulsion principle would work just as well in a perfect vacuum—though, of course, some way would have to be found to support the plane and provide the air for the operation of the jet propulsion turbine."

R. H. O.

Foreign Nations Begin Study of American Automotive Production Methods.—Battle performance of American motor vehicles is currently causing both friend and enemy alike to take a closer look at this country's automotive mass production methods, the Automotive Council for War Production stated recently.

The significance of United States motorized equipment as a major factor in turning the tide against the Axis is underscored by Field Marshall Albert Kesselring, German Army Commander in Italy. In a statement explaining his failure to his superiors, a copy of which was captured by American forces, Kesselring said:

"The performance of enemy tanks and motor vehicles was astoundingly good."

Recent Lend-Lease figures place further emphasis on the war role of American vehicles, the Council pointed out. Since the beginning of Lend-Lease in March, 1941, such equipment has constituted roughly one-third of the total of all goods supplied by the United States to the rest of the United Nations.

As a result, not only the Axis, but the other United Nations have been impressed by the tremendous volume of high quality war vehicles of all types, and have begun to investigate the peacetime production methods and principles which made this record American automotive output possible, statements from abroad indicate.

In studies of the problem by the British sóme startling contrasts were uncovered. For example, they discovered that although American labor costs per hour ran twice their own during the immediate pre-war years, the price of vehicles in the United States steadily declined while quality increased.

Comparing the costs of materials used in a representative English vehicle and those used in a similar American product, the British found that without exception their prices ran considerably higher.

Along this line they discovered that a steering wheel cost the British manufacturer 81 per cent. more than it did the American producer. A starter cost 79 per cent. more, a distributor 59 per cent. more, a crankshaft 127 per cent. more, while malleable iron castings and steel body sheets cost just twice what the American car builder paid for the same product.

R. H. O.

Properties and Current Applications of New Coated Glass Fabrics Indicate Many Uses.—Properties and current applications of the first commercially available Fiberglas fabrics coated on one or both sides with synthetic rubbers or resins indicate a wide field of use for these materials, according to Owens-Corning Fiberglas Corporation.

Coatings employed to date are Neoprene, Koroseal, and Vinyl resins. Application of a properly selected coating to the glass fabric results in a material with high dimensional stability and tear strength, and substantially increased flexing resistance. Uncoated glass fabrics are not recommended for applications involving continuous or severe flexing, but experience to date with some of the coated fabrics indicates that they may be used satisfactorily under flexing conditions that would destroy an uncoated fabric by internal abrasion.

Experimental Weaves. In addition to the all-glass fabrics to which coatings have been applied, experimental weaves have been developed using Fiberglas yarns for the warp and cotton yarns for the fill. The purpose of the glass-cotton combination is to provide high strength in one direction, with the glass taking the load and the cotton holding the glass yarns in position.

By using such a fabric as reinforcement for plastic laminates, with each layer of cloth laid crosswise to the preceding layer, laminates that are equally strong in both directions can be fabricated. A similar application may find value in coated fabrics where maximum tensile strength is sought.

Glass-Asbestos Cloths. Combination glass and asbestos cloths are now commercially available in limited quantities and may prove suitable as a base for coated fabrics. However, their properties as coated fabrics have not been explored. Fundamentally, glass-asbestos fabrics combine the strength of glass yarns with the bulk, felting properties and flex resistance of asbestos yarns.

Present uses of all-glass coated fabrics include aircraft battery covers, zippered boots for tanks, oil pressure switch diaphragms, aircraft tape for expansion joints of hot air ducts, protective aprons for workers in chemical plants. Resistance to heat, acids or oils is an important factor in these applications.

Suggested future uses include tents for the armed forces, water and gasoline tanks and bags, delousing bags, aircraft engine covers, pressurized bags for metal bonding, carburetor diaphragms, weather-proof containers for delicate machinery and instruments.

R. H. O.

New Fire-Resistant Glass Fiber-Resin Laminate Specified For Electrical Control Panels on U. S. Navy Ships.—To minimize the possibility of fire which could put the entire electrical system of a fighting ship out of commission, the Navy Department, Bureau of Ships, has issued a directive requiring use on Navy ships of a fire-resistant, glass fiber-reinforced plastic material for panel boards on which electrical control instruments are mounted.

The new-type panel board material is a laminate built up of many layers of cloth woven of fibrous glass yarns, and impregnated and bonded with a melamine resin. It is the result of research initiated by the Navy Department before Pearl Harbor, and carried on with the cooperation of fabricators and manufacturers of electrical control equipment, who had to solve many difficult design problems created by the physical properties of the new material.

In addition to being fire resistant, the fibrous glass and melamine combination has high impact strength and high resistance to the carbonizing effect of the electric arc—a condition that occurs when current jumps, or arcs, from one terminal to another across the board. Severe arcing could itself be responsible for panel board fires which, destroying the electrical system, would leave the ship out of control.

R. H. O.